Fecal Coliform TMDL for Naked Creek in Augusta and Rockingham Counties, Virginia

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Located in Augusta and Rockingham Counties in Virginia, the Naked Creek watershed (VAV-B28R, 14,674 acres) is approximately 5 miles north of the city of Staunton and 5 miles south of Harrisonburg. Naked Creek is a tributary of North River. The North River is a tributary of the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005), which in turn, is a tributary of the Potomac River. The Potomac River discharges into the Chesapeake Bay.

Water quality samples collected in Naked Creek, over a period of eleven years (July 1990 – February 2001) indicated that 45% of the samples violated the instantaneous water quality standard for fecal coliform. The instantaneous standard specifies that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the frequency of water quality violations, Naked Creek has been placed on Virginia's 1998 303(d) list of impaired water bodies for fecal coliform. The impairment starts at the headwaters and continues downstream to its confluence with North River, for a total of 6.75 stream miles.

As a result of the water quality impairment, Naked Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b). In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of fecal coliform and a margin of safety (MOS). The TMDL was developed for the geometric mean water quality standard for fecal coliform, which states that the 30-day geometric mean concentration of fecal coliform shall not exceed 200 cfu/100 mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.2. Sources of Fecal Coliform

There are two point sources permitted to discharge fecal coliform in the Naked Creek watershed, however the majority of fecal coliform load is originated from nonpoint sources. The nonpoint sources of fecal coliform are mainly agricultural, such as, land-applied animal waste and manure deposited on pastures by cattle. A significant fecal coliform load comes from cattle directly depositing in streams. Wildlife contributes to fecal coliform loadings on pasture, forest, and in streams. Non-agricultural nonpoint sources of fecal coliform loadings include failing septic systems and pet waste. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in production and practices, considering factors such as the fraction of time cattle are in confinement, time spent in streams, and manure storage and spreading schedules.

1.3. Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Naked Creek watershed. The BASINS (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 3.0 interface was used to facilitate use of HSPF. To identify localized sources of fecal coliform within the Naked Creek watershed, the watershed was divided into ten sub-watersheds, based on homogeneity of land use.

Due to the lack of flow data for Naked Creek, the hydrology component of HSPF was calibrated for Linville Creek, a tributary of North Fork of the Shenandoah River. The Naked Creek and Linville Creek watersheds have similar land use characteristics. The HSPF model was calibrated for Linville Creek using data from a 4.5-year period. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions as well as seasonal variations. The calibrated HSPF data set was validated on a separate period of record for Linville Creek (5 years). The calibrated HSPF model adequately simulated the hydrology of the Naked Creek watershed.

The water quality component of the HSPF model was calibrated using over nine years (July 1991 – December 2000) of fecal coliform data collected in the watershed. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate of fecal coliform in the watershed.

1.4. Margin of Safety

While developing allocation scenarios to implement the TMDL, an explicit margin of safety (MOS) of 5% was used. Hence, the maximum 30-day geometric mean target for the allocation scenario was 190 cfu/100 mL, 5% below the standard (200 cfu/100 mL). It is expected that a MOS of 5% will account for any uncertainty involved in the accuracy of the model.

1.5. Existing Conditions

Based on amounts of fecal coliform produced in different locations, monthly fecal coliform loadings to different land use categories were calculated for each sub-watershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal fecal coliform loadings to streams by cattle were calculated for pastures adjacent to streams. Fecal coliform loadings to streams and land by wildlife were estimated for several species. Fecal coliform loadings to land from failing septic systems were estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered.

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative hydrologic period of four years (January 1994 – December 1997). The simulation results indicated that the mean daily fecal coliform concentration at the watershed outlet was 2,383 cfu/100 mL compared with an average fecal coliform concentration of 1,918 cfu/100mL observed during the simulation period. Since the water quality samples had caps of 8,000 cfu/100 mL (before February 1995) or 16,000 cfu/100 mL, the average observed value could have been higher. Nearly 67% of the fecal coliform in the mean daily fecal coliform concentration comes from cattle directly depositing in the stream, 29% from upland areas due to runoff, and wildlife defecating in the stream accounts for the remaining 4%. Observed and simulated fecal coliform concentrations exceeded the 30-day geometric mean water quality standard more frequently during low flow periods and the summer. During the summer when stream flow was lower, cattle spent more time in streams, and thereby, increased direct fecal coliform deposition to streams when water for dilution was least available.

1.6. Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet the 30-day geometric mean criterion, including a margin of safety, (190 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

Table 1.1. Allocation scenarios for Naked Creek watershed.

Scenario Number	Number of Violations of 190 cfu/100mL Goal	Violation Frequency %	Required Reduction, %			
			Cattle Direct Deposit	Wildlife Direct Deposit	Straight-Pipes	NPS Loadings from Pervious Land Segments
00	351	24.02	95	0	100	0
01	31	2.12	100	0	100	0
02	24	1.64	100	0	100	50
03	24	1.64	100	0	100	60
04	20	1.37	100	0	100	80
05	6	0.41	100	0	100	95
06	20	1.37	100	10	100	0
07	12	0.82	100	15	100	0
08	3	0.21	100	25	100	0
09	**0**	**0.00**	**100**	**30**	**100**	**30**
10	1	0.07	99.5	45	100	30

A comparison of Scenarios 0 and 1 clearly illustrates that direct cattle deposit in the stream has a significant impact on fecal coliform concentrations. Comparison of Scenarios 2 through 5 indicate that nonpoint source loading from upland areas is a minor source of fecal coliform compared to the impact of the loading of cattle in-stream on the water quality standard violation rate. The results obtained for Scenarios 6, 7 and 8 indicate that there is a need to reduce contributions from all sources to meet the water quality standard. While Scenario 10 almost meets the TMDL allocation requirement of zero violations of the 30-day geometric mean, it is difficult to implement. Scenario 9, the selected allocation scenario, represents a reasonable compromise since it minimizes the required wildlife load reductions. Scenario 9 requires a complete elimination of contributions from direct pipes and cattle in streams. The required load reductions for the TMDL allocation for wet weather nonpoint sources are listed in Table 1.2 and direct nonpoint sources in Table 1.3. The 30-day geometric mean fecal coliform concentrations resulting from Scenario 9, as well as the existing conditions, are presented graphically in Figure 1.1.

Table 1.2. Annual nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 9)[a].

Land use Category	Existing Conditions		Allocation Scenario	
	Existing load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	24.4	0.64%	17.1	30%
Pasture 1	1,976	51.62%	1,383	30%
Pasture 2	1,795	46.87%	1,256	30%
Residential [b]	31.7	0.83%	22.2 [c]	30%
Forest	1.5	0.04%	1.5	0%
Total	3,829	100%	2,680	30%

[a] Loads listed from upland areas represent edge of stream loads.

[b] Includes loads applied to both High and Low Density Residential and Farmstead

[c] Reduction only applies to Low Density Residential and Farmstead Areas (Not to High Density Residential Areas because the loadings from these areas were considered negligible)

Table 1.3. Annual direct nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 9).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	31.3	94.6%	0	100%
Straight-Pipes	0.6	1.8%	0	100%
Wildlife in Streams	1.2	3.6%	0.84	30%
Total	33.1	100%	0.84	97%

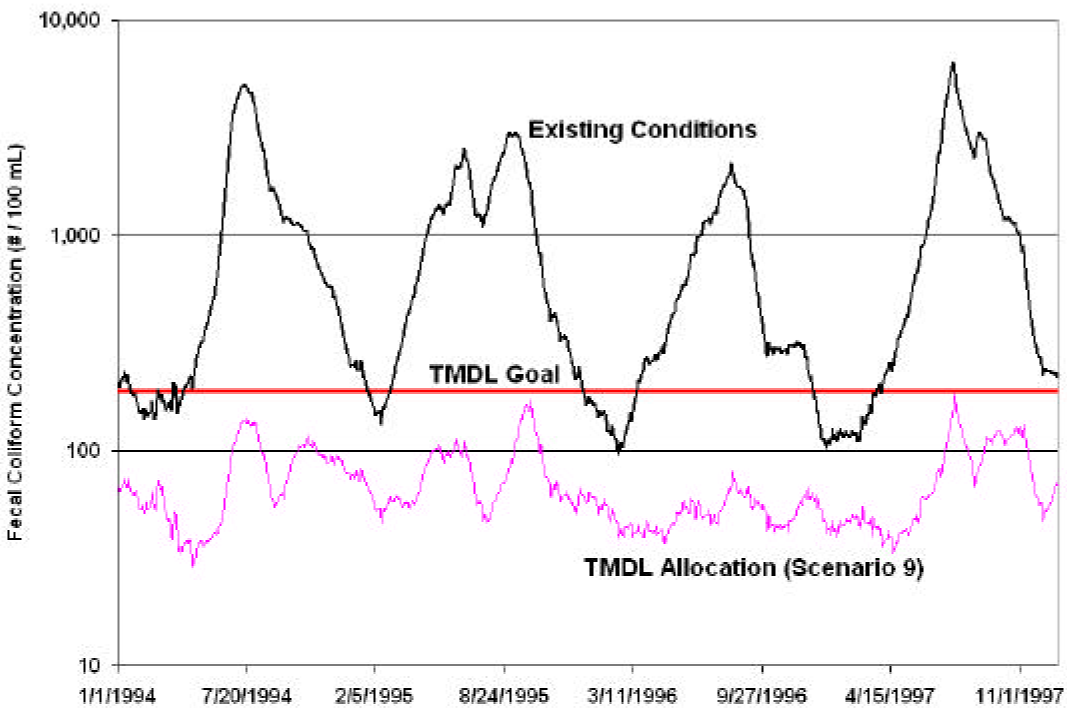

Figure 1.1. Successful TMDL allocation, 190cfu/100mL geometric mean goal, and existing conditions for Naked Creek (Scenario 9, Table 1.1).

For the selected scenario (Scenario 9), load allocations were calculated using the following equation.

$$\text{TMDL} = \text{SWLA} + \text{SLA} + \text{MOS} \qquad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, 5% of TMDL.

There are two permitted point sources of fecal coliform in the Naked Creek watershed that are discharging at or below their permit requirements, the proposed scenario requires load reductions for nonpoint sources of fecal coliform. Based on reductions required from existing conditions and fecal coliform loadings given in Table 1.2 and Table 1.3, the summary of fecal coliform TMDL is given in Table 1.4.

Table 1.4. Annual fecal coliform loadings (cfu/year) used for the Naked Creek fecal coliform TMDL.

Parameter	SWLA	SLA	MOSa	TMDL
Fecal coliform	0.006×10^{12}	$2{,}681 \times 10^{12}$	141×10^{12}	$2{,}822 \times 10^{12}$

[a] Five percent of TMDL

The proposed scenario requires the 30% reduction in fecal coliform loads from pervious, upland sources and 30% reduction from wildlife. Further, complete exclusion of cattle from streams and elimination of discharge from direct pipes to the stream are required to meet the TMDL goal.

1.7. Phase 1 Implementation

An alternative scenario was evaluated to establish a first phase for the implementation of the TMDL. The implementation of such a transitional scenario, or Phase 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Phase 1 implementation was developed for a maximum of 10% violation rate of the instantaneous water quality standard (1,000 cfu/100 mL) based on monthly sampling frequency. Phase 1 implementation requires a 75% reduction in direct fecal coliform loading by cattle in-stream and elimination of direct discharge by direct pipes. Also, a 20% reduction in fecal coliform loadings from the pervious, upland areas is required. The Phase I implementation requires no reductions from wildlife.

1.8. Reasonable Assurance of Implementation

1.8.1. Follow-Up Monitoring

The Department of Environmental Quality will continue to monitor Naked Creek in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

1.8.2. Regulatory Framework

This TMDL is the first step toward the expeditious attainment of water quality standards. The second step will be to develop a TMDL implementation plan, and the final step will be to implement the TMDL until water quality standards are attained.

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "*develop and implement a plan to achieve fully supporting status for impaired waters*". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft

Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.8.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA's CREP program, the state revolving loan program, and the VA Water Quality Improvement Fund.

1.9. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. On June 6, 2001, members of the Virginia Tech TMDL group traveled to Augusta County to become acquainted with the watershed. During that trip, Virginia Tech TMDL group spoke with various stakeholders. In addition personnel from Virginia Tech, the Headwaters SWCD, and NRCS visited watershed residents to acquire their input. Two public meetings were held. The first public meeting was organized on October 25, 2001, at Bethany United Methodist Church, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates and to discuss the hydrologic calibration. The draft TMDL report was discussed at the final public meeting held on February 28, 2002.

CHAPTER 2: INTRODUCTION

2.1. Background

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Since fecal material may contain pathogenic organisms, water bodies with high fecal coliform counts are potential sources of pathogenic organisms. For contact recreational activities, e.g., boating and swimming, health risks increase with increasing fecal coliform counts in the water body. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state fecal coliform standard for contact recreational uses.

The Virginia Department of Environmental Quality (VADEQ) has identified Naked Creek as being impaired by fecal coliform for a stream length of 6.75 miles, beginning at the headwaters and continuing downstream to its confluence with North River. Naked Creek has been accorded high priority on the list for TMDL development and was targeted for completion during 2000-2002.

A part of the North River basin, Naked Creek watershed (Watershed ID VAV-B28R) is located in Augusta and Rockingham Counties of Virginia, about 5.0 miles north of Staunton and 5 miles south of Harrisonburg (Figure 2.1). The watershed is 14,674 acres in size. Naked Creek is mainly an agricultural watershed (about 68.5%) and is characterized by a rolling valley with the Blue Ridge Mountains on the east and the Appalachian Mountains on the west. The majority of the remaining 31.5% of the watershed area is divided between forest and rural developments. Naked Creek flows southeast and discharges into the North River, which in turn, confluences with the South River forming the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005). The South Fork of the Shenandoah River is a tributary of the Shenandoah River, a tributary of the Potomac River; the Potomac River discharges into the Chesapeake Bay.

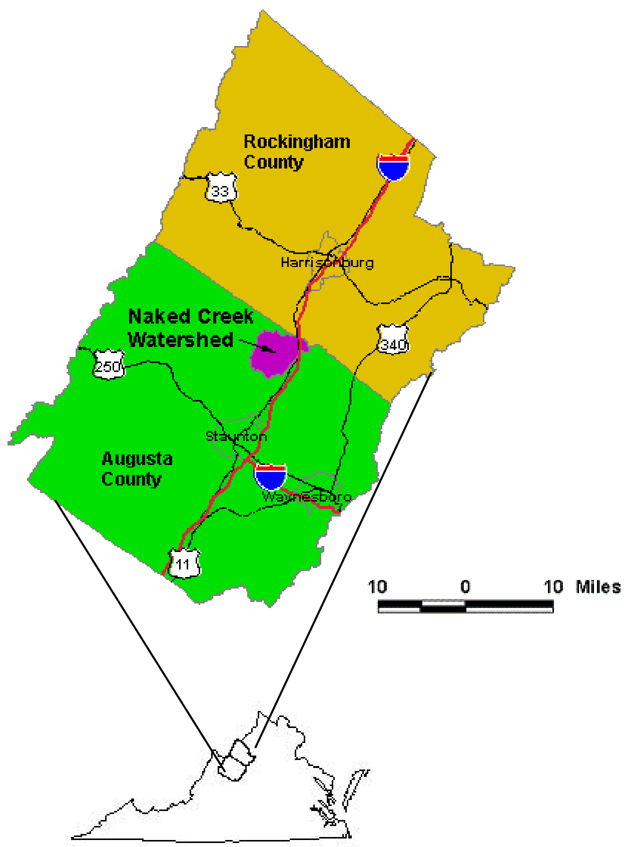

Figure 2.1. Location of Naked Creek watershed.

2.2. Applicable Water Quality Standards and Critical Conditions

For a non-shellfish supporting water body to be in compliance with Virginia fecal coliform standards for contact recreational use, VADEQ specifies the following standards (9 VAC 25-260-170):

- Instantaneous standard: Fecal coliform count shall not exceed 1,000 colony forming units (cfu) per 100 mL at any time, or
- Geometric mean standard: The geometric mean count of fecal coliform of two or more water quality samples taken within a 30-day period shall not exceed 200 cfu/100 mL.

If the water body exceeds either standard more than 10% of the time, the water body is classified as impaired and a TMDL must be developed and implemented to bring the water body into compliance with the water quality standard. Based on the sampling frequency, only one standard is applied to a particular datum or dataset (9 VAC 25-260-170). If the sampling frequency is one sample per 30 days or less, the instantaneous standard is applied; for a higher sampling frequency, the geometric mean standard is applied. For the Naked Creek watershed, the TMDL is required to meet the geometric mean standard. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land use heterogeneity, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

2.2.1. Water Quality Standards Review

Two regulatory actions related to the fecal coliform water quality standard are currently under way in Virginia. The first rulemaking pertains to the indicator species used to measure bacteria pollution. The second rulemaking is an evaluation of the designated uses as part of the state's triennial review of its water quality standards.

Indicator Species

EPA has recommended that all States adopt an E. coli or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. EPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (E. coli and enterococci) and the incidence of gastrointestinal illness than with fecal coliform. E. coli and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the E. coli and enterococci standard is scheduled for 2002 in Virginia.

Designated Uses

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard is described in 9 VAC 25-260-170 as stated earlier in this report. This standard is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use.

In the TMDL public participation process, the residents in these watersheds often report that "*people do not swim in this stream*." It is obvious that many streams within the state are not used for recreational purposes.

Additionally, VADEQ and VADCR have developed fecal coliform TMDLs for a number of impaired waters in the State. In some of the streams, fecal coliform bacteria counts contributed by wildlife result in standards violations, particularly during base flow conditions. Wildlife densities obtained from the Department of Game and Inland Fisheries and analysis or “typing” of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl contribute to elevated fecal bacteria counts in these streams (Maptech, 2000; Mostaghimi et. al., 2000).

Recognizing that all waters in the Commonwealth are not used extensively for swimming, VA is considering re-designation of the swimming use for secondary contact in cases of: 1) natural contamination by wildlife, 2) small stream size and 3) lack of accessibility to children. The widespread socio-economic impacts resulting from the cost of improving a stream to a "*swimmable*" status are also being considered.

The re-designation of the current swimming use in a stream to a secondary contact use will require the completion of a Use Attainability Analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use, which may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and EPA will have an opportunity to comment on these special studies.

2.3. The Water Quality Problem

The Naked Creek watershed supports a fairly large animal population, comprised mainly of cattle and poultry; and most of the animal waste generated is applied to agricultural lands within the watershed. The Virginia Department of Conservation and Recreation (VADCR) has assessed this watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 92 water quality samples collected during July 1991 – April 2001 at the outlet of the watershed, 45% of the samples exceeded the instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of Naked Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b).

2.4. Objective

The objective of the project was to develop a TMDL for the Naked Creek watershed that accounts for both point and nonpoint source pollutant loadings and incorporates a margin of safety to meet the zero percent violation of the state geometric mean standard for fecal coliform for non-shellfish waters. The following tasks were performed to achieve the project objective.

Task 1. Identified potential fecal coliform sources, including background sources, and estimated the magnitude of each source in cooperation with stakeholders;

Task 2. Quantified fecal coliform production from each source;

Task 3. Simulated attenuation of fecal coliform during storage and transport from deposited or applied locations to water bodies;

Task 4. Accounted for variations in precipitation, hydrology, and land use in simulating fecal coliform fate in streams;

Task 5. Estimated fecal coliform concentrations in water bodies under present conditions;

Task 6. Explored multiple scenarios to reduce fecal coliform concentrations to meet the geometric mean water quality standard;

Task 7. Selected a TMDL that can be realistically implemented and is socially acceptable; and

Task 8. Incorporated a margin of safety into the TMDL.

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

The Naked Creek watershed was subdivided into 10 sub-watersheds shown in Figure 3.1. Tributaries to the impaired segment (Naked Creek B28-1, 4, 6, 9, 10) include Goose Creek, (B28-8), Byers Branch (B28-2, 3) and the North Fork of Naked Creek (B28-5, 7). Most streams in these smaller sub-watersheds flow seasonally/intermittently through pasture areas. Banks are typically steep and deep, with a trapezoidal channel cross-section. Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is in excess of 6 ft (SCS, 1985). The presence of numerous karst features and intense agricultural use result in a high potential for groundwater pollution (VWCB, 1985).

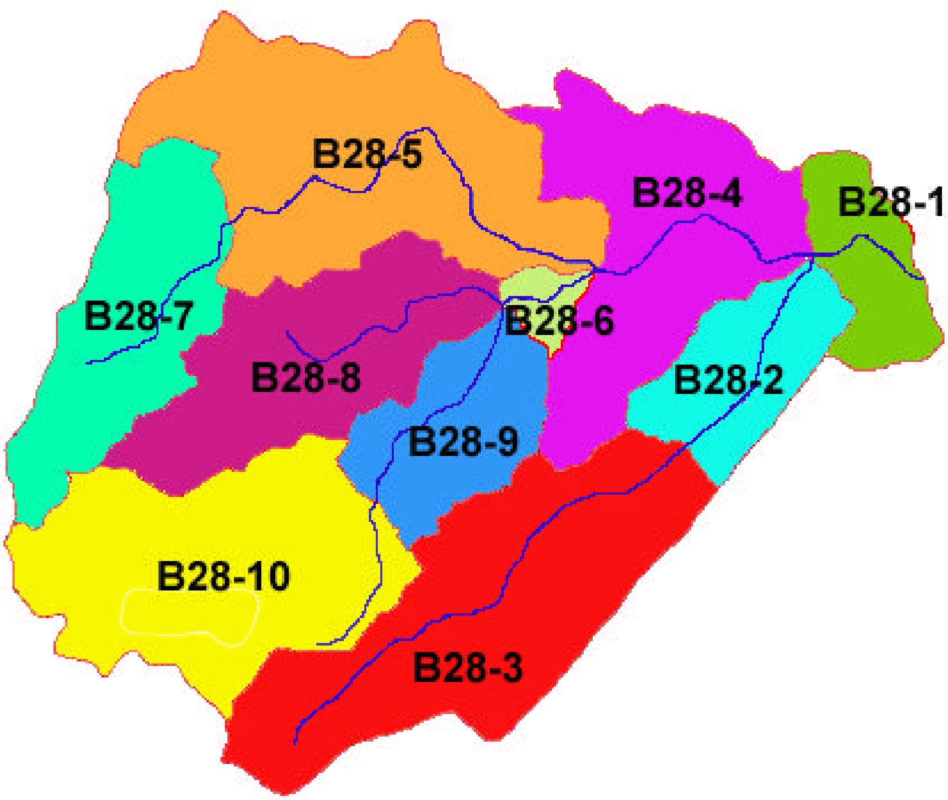

Figure 3.1. Naked Creek sub-watersheds and stream network.

3.2. Soils and Geology

The main soil associations found in Naked Creek watershed are the Frederick-Christian-Rock outcrop, Frederick-Bolton-Christian (SCS, 1979) and Frederick-Lodi-Rock outcrop soils (SCS, 1985). Soils in the watershed are characterized as deep to moderately deep well drained soils with clay loam to clay subsoils, or gravelly loam to gravely clay loam on limestone uplands. The Frederick-Lodi-Rock outcrop (silty loam) soils are deep and well drained with clayey subsoil and areas of rock outcrop. Permeability of Frederick and Lodi soils is moderate with medium to rapid surface runoff. These soils are found on gently sloping to steep topography (NRSCS, 1985). In upland areas, the Frederick-Lodi-Rock outcrop soils are underlain by deep limestone and dolomitic limestone bedrock (SCS, 1985). This karst bedrock has numerous cracks, fissures and caves capable of transporting water and contaminants considerable distances before resurfacing as spring water or baseflow.

3.3. Climate

Because there are no weather stations within the watershed, climate is characterized based on the meteorological observations made by the National Weather Service's cooperative observer at the nearby Staunton Sewage Treatment Plan, located South of the Naked Creek watershed. Average annual precipitation is 36.2 inches with 65% of the precipitation occurring from April-October, which includes the crop-growing season (VSCO, 2002). Average annual snowfall is approximately 24.6 inches. Average annual daily temperature is 52.3F. The highest average daily temperature of 72.5°F occurs in July, while the lowest average daily temperature of 30.9°F occurs in January (VSCO, 2002).

3.4. Land use

Using remotely-sensed data, specifically, Carterra imagery consisting of 1996, 1997, and 1998, five-meter resolution panchromatic Indian Remote Sensing – 1C(IRS-1C) satellite images fused with 1997 thirty-meter resolution Landsat 5 color infrared satellite imagery, VADCR developed a digital land use coverage and identified twelve land use types in the Naked Creek watershed. The twelve land use categories were consolidated into seven categories based on similarities in hydrologic and waste application/production features (Table 3.1). Hydrologic similarity was defined in terms of percent perviousness (imperviousness). Similarity in waste application/production was determined based on potential sources of fecal coliform that could be expected to be present on the land use type. Pasture comprises most of the area in Naked Creek and covers about 64% of the total watershed area (Table 3.2). Cropland accounts for about 4.5% of the watershed area. Forest acreage accounts for about 30%, while residential land use accounts for less than 1% of the total area.

The watershed was divided into ten sub-watersheds to spatially analyze waste or fecal coliform distribution within the watershed (Figure 3.1). These ten sub-watersheds were used in the modeling activities. However, sub-watershed NC-06 was combined with sub-watershed NC-05 for the calculations of the fecal coliform sources. This was done because of the relatively small area of sub-watershed NC-06. The main purpose for delineating sub-watershed NC-06 was to preserve the connectivity of the reach network in the watershed. It was felt that the relatively small size of sub-watershed NC-06 may exaggerate the load contributions originating in that area. Information on land use distribution in the sub-watersheds as well as in the entire Naked Creek watershed is presented in Table 3.2.

Table 3.1. Land use categories for Naked Creek watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (Percentage)	VADCR Land Use Categories
Cropland	Pervious (100%)	Row Crops Gullied Row Crops Row Crops Stripped Rotational Hay Orchard
Pasture 1	Pervious (100%)	Improved Pasture/Hayland Pasture
Pasture 2	Pervious (100%)	Unimproved Pasture Grazed Woodland
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry Farmstead Farmstead with Dairy Waste Facility Poultry Facility Dairy Beef Farm Large Individual Dairy Waste Facility
Low Density Residential	Pervious (72%) Impervious (28%)	Built-Up > 50% Porous Rural Residential Wooded Residential
High Density Residential	Pervious (25%) Impervious (75%)	Built-Up < 50% Porous Sewered Residential Unclassified Transitional and Disturbed Sites
Forest	Pervious (100%)	Forest Recently Harvested Woodland-Clear Cut Recently Harvested Woodland-Not Clear Cut Unmanaged Grass and Shrubs Water Nurseries and Christmas Tree Farms

[a] Percent perviousness/imperviousness information was used in modeling (described in Chapter 5)

Table 3.2. Land use distribution in Naked Creek watershed (acres).

Land use	Sub-watershed									Total
	B28 1	B28 2	B28 3	B28 4	B28 5,6	B28 7	B28 8	B28 9	B28 10	
Cropland	29	141	122	121	183	2	16	23	23	660
Pasture 1	338	163	1,433	899	1,657	792	1,085	611	1,207	8,185
Pasture 2	32	227	142	264	126	5	114	112	237	1,259
Farmstead	6	7	14	38	22	2	12	4	17	122
Low Density Residential	0	4	0	5	2	0	0	0	0	11
High Density Residential	2	20	10	26	45	0	0	1	0	104
Forest	197	235	724	495	779	622	353	175	754	4,333
Total	605	796	2,444	1,847	2,815	1,424	1,580	925	2,237	14,674

3.5. Water Quality Data

3.5.1. Fecal coliform concentrations

VADEQ personnel monitor fecal coliform concentrations at the Naked Creek watershed outlet (DEQ Station ID No. 1BNKD000.80) (Figure 3.2). The data collected from July 1991 to February 2001 was used in preparing this TMDL. A complete listing of the fecal coliform observations available from DEQ is listed in Appendix I. These data are presented graphically as a time series in Figure 3.3.

The Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN analysis procedures employed by VADEQ had a maximum detection limit of 8,000 cfu/100 mL. Over 45 percent of the 92 water samples collected by VADEQ during the collection period contained fecal coliform concentrations in excess of the instantaneous standard of 1,000 cfu/100 mL (Figure 3.3). Water samples were collected too infrequently to calculate a geometric mean applicable to the 200 cfu/mL standard.

The seasonality of fecal coliform concentration in the streams was evaluated by grouping fecal coliform concentration values by seasons and then determining the frequency of exceedances of the instantaneous water quality standard (Figure 3.4). The analysis used fecal coliform concentration data from the 1991 through 2001 period.

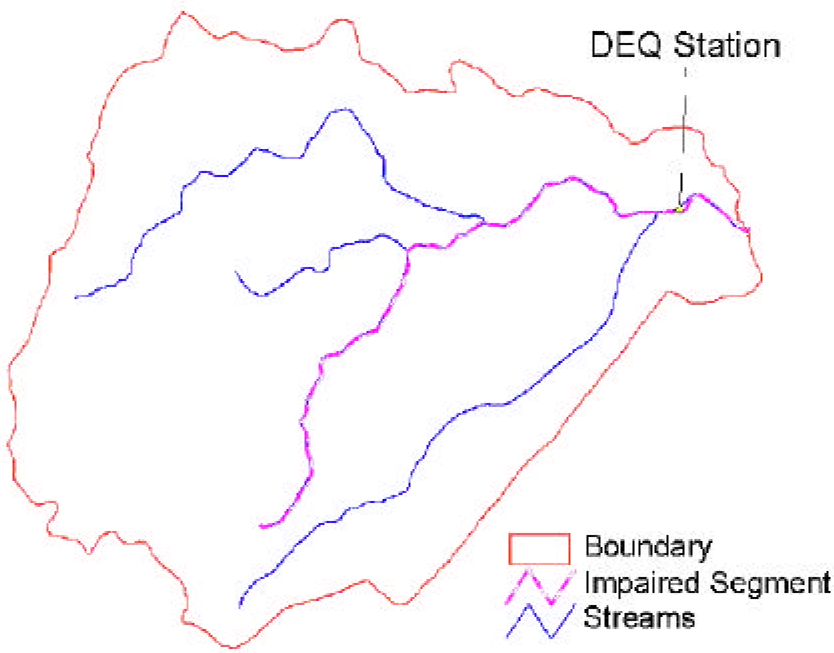

Figure 3.2. Location of VADEQ monitoring station for water quality samples on Naked Creek.

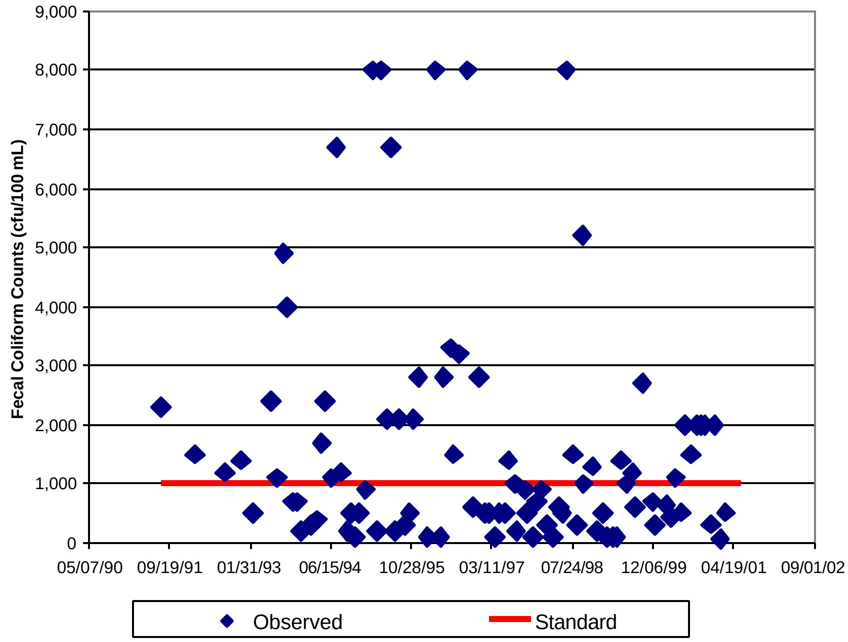

Figure 3.3. Time series of fecal coliform concentration in Naked Creek.

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and lower concentrations typically occurring during the winter months. During summer (June – August), the average fecal coliform concentration was 2203 cfu/100mL compared with 633 cfu/100mL during winter (December – February). It should be noted that because of the upper limit of 8000 imposed on the fecal coliform counts, the actual counts could be much higher than the computed average values. Lower fecal coliform concentrations measured during the winter and spring months (Figure 3.4) could be due to larger number of animals being in confinement during these periods, resulting in smaller fecal coliform loading to the pasture, and particularly to streams. Furthermore, land application of animal waste is limited during the winter months. Also, stream flows during winter and spring tend to be higher than summer and fall flows resulting in increased stream flow for dilution. As shown in Figure 3.4, the highest violation of the instantaneous standard occurred during the summer months when stream flows are expected to be the lowest.

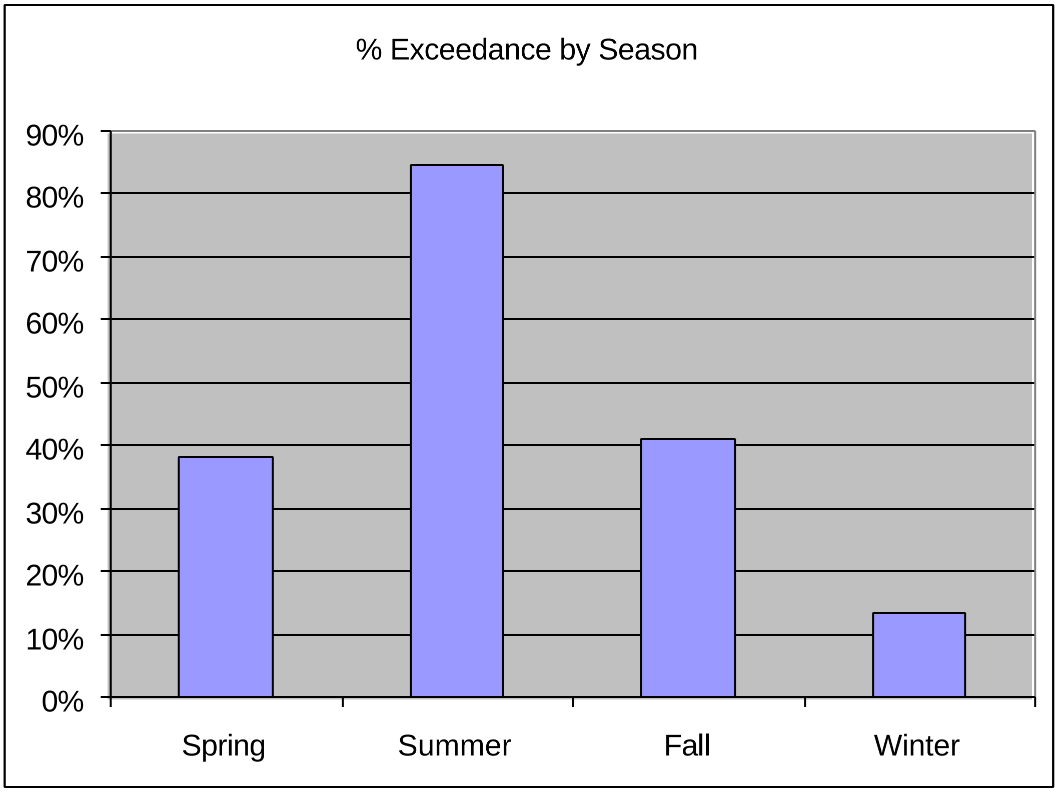

Figure 3.4. Impact of seasonality on violation of instantaneous standard for fecal coliform in Naked Creek.

3.5.2. Bacteria Source Tracking

Bacteria source tracking (BST) was conducted to aid in identification of sources of fecal bacteria in the Naked Creek watershed. The BST samples were collected at four locations in the watershed, as shown in Figure 3.5. The Antibiotic Resistance Analysis (ARA) procedure was used in this study (Hagedorn et al., 1999). The monthly BST samples were collected from June through December 2001, for a total of seven months. A total of 28 samples were collected from the four stations. It should be noted that this short sampling period was characterized by below normal precipitation, warm temperatures, and low stream flows. In fact on several occasions no samples were collected at some stations due to the very low or no stream flows. The short time-frame available for field sample collection and the resulting small number of samples collected makes it difficult to draw any firm quantitative conclusions regarding bacteria sources in the Naked Creek watershed. However, the information does provide insight into likely sources of fecal contamination in the Naked Creek and will assist with the selection of appropriate scenarios to meet the TMDL requirements. The BST data could also be useful in the implementation phase of the Naked Creek TMDL.

A total of 48 isolates were analyzed for each BST sample. Isolates from several known sources (poultry, dairy, beef, goats and human) in the watershed were collected to enhance the source database and improve the accuracy of the results for the Naked Creek watershed. The ARA results are reported as the percentage of isolates acquired from samples that were identified as originating from either human, livestock or wildlife sources (Table 3.3). Results indicate that livestock is the major contributor of fecal coliform to Naked Creek. Wildlife was also determined to be a significant contributor, followed by human sources (Table 3.3). It should be noted that several years of field BST data might be needed to evaluate the long-term impact of the variations in climate and land use. All the BST samples in the Naked Creek watershed were collected during extremely low stream flow conditions and warm temperatures, which precluded a comprehensive assessment of the impacts of land-based (manure applications, direct deposits) sources. Furthermore, due to the short term available for BST sample collection, no evaluation of the seasonal impacts could be made. Therefore, the results presented here should be used with caution, as they may not be representative of general watershed conditions. Expanded information on the BST results is included in Appendix F.

Table 3.3. Naked Creek BST results for general categories.

Station	Fecal Coliform Concentration (cfu/100mL)	General Categories (%)		
		Human	Livestock	Wildlife
NC1	690	20.5	56.0	23.5
NC2[1]	4,080	0.0	72.6	27.4
NC3[2]	1,225	3.1	61.7	35.2
NC4	477	14.4	56.4	29.3

[1] Only one sample was collected due to stream being dry.
[2] Only two samples were collected due to stream being dry.

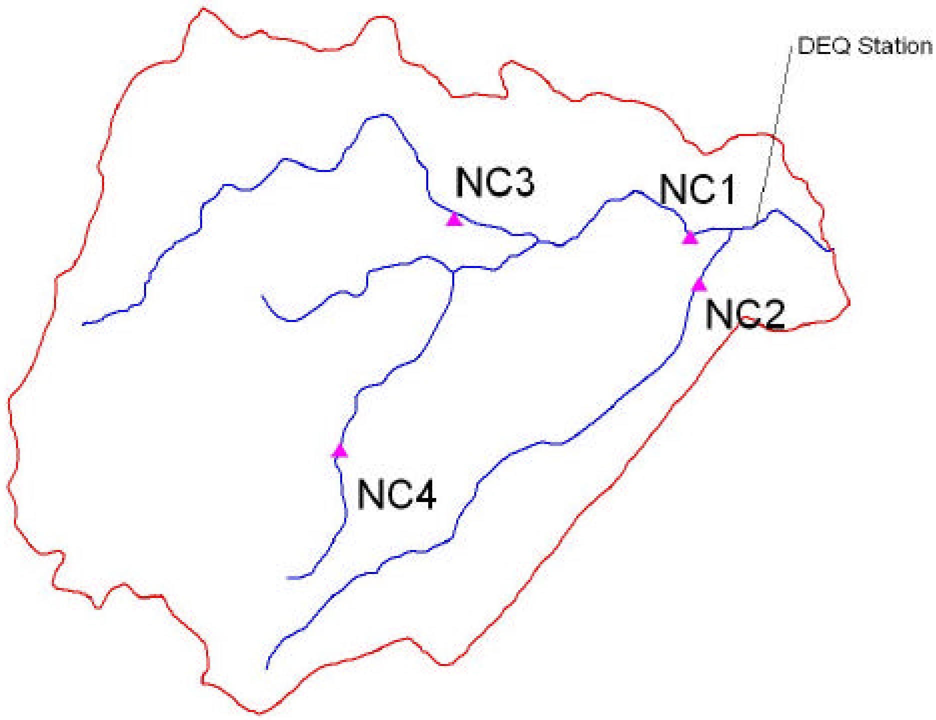

Figure 3.5. Location of BST monitoring stations for Naked Creek.

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Potential fecal coliform sources in the Naked Creek watershed were assessed using multiple approaches, including information from VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), VCE, NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. There were three permitted point sources in the watershed (Table 4.1). Only two of the point sources are permitted to discharge fecal coliform under a general permit to discharge 1,000 gallons per day with a concentration of 200 cfu/100mL (C. Martin, personal communication, 10 October 2001, Richmond, Va.). The fecal coliform production rates for potential sources are listed in Table 4.2. Potential nonpoint sources of fecal coliform are described in detail in the following sections.

Table 4.1. Permitted Point Sources in the Naked Creek Watershed.

VA Permit ID	Permitted FC Discharge (Yes/No)	Maximum Discharge Rate (gpd)	FC Permit Limit (cfu/100 mL)	Wasteload Allocation (cfu/year)	Sub Water-shed
VAG401165 [a]	Yes	1,000	200	2.76×10^9	B28-01
VAG401545 [a]	Yes	1,000	200	2.76×10^9	B28-02
VA0088188	No	1,000	0	0	B28-01

[a] General VPDES Permit

4.1. Humans and Pets

Naked Creek watershed has an estimated population of 1,409 people (587 households at 2.4 people per household). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

Table 4.2. Potential fecal coliform sources and daily fecal coliform production by source in Naked Creek watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	1,409	1,950[a]
Dairy cattle Milk and dry cows Heifers [c]	630	 20,000[b] 9,200[d]
Beef cattle	3,540	25,800[e]
Pets	587	450[f]
Poultry Broilers Broiler Breeders Breeder Turkeys[i] Turkey Hens[i] Turkey Toms	 566,000 44,000 50,500 408,500 109,000	 136[g] 89[g] 93[g]
Sheep Ewe Sheep Lamb Goats	 690 1,380 170	 12,000[g]
Horse	375	420[g]
Deer	691	347[i]
Raccoon	354	113[i]
Muskrat	1,257	25[i]
Beaver	34	0.3[j]
Wild Turkey	144	93[g]
Duck	45	2,430[g]
Geese	30	799[i]

[a] Source: Geldreich et al. (1977)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[f] Source: Weiskel et al. (1996)
[g] Source: ASAE (1998)
[h] Converted to equivalent population of Tom Turkeys (procedure discussed in Chapter 4)
[I] Source: Yagow (1999)
[j] Source: MapTech, Inc. (2000)

4.1.1. Biosolids

Biosolids produced at the Harrisonburg Wastewater Treatment Plant were applied to cropland and pasture lands in the Naked Creek watershed. Information on the biosolids applications and permits were provided by the VADEQ and VDH. The biosolids were applied twice, 1998 and 2000, during the period considered when developing the TMDL plan (July 1991 through December 2000). A total of

70 acres in the Naked Creek watershed were permitted to receive biosolids applications. Assuming maximum allowable fecal coliform content (1,995,262 cfu/gram, VDHBUR 1997) and that all 70 acres received biosolids every year at the allowable application rate of 15 dry tons per acre per year, the fecal coliform load applied in the Naked Creek watershed from biosolids would be much less than 0.1% of the total fecal coliform load applied to the pasture and cropland areas. In addition, because of incorporation of biosolids after application to cropland, only 10 to 30% of the applied biosolids to cropland would be available for transport. The reality is that: (1) only a few fields, much less than total permitted 70 acres, received biosolids; (2) the fields only received biosolids once or twice during the simulation period (not every year as assumed); (3) the actual concentrations of fecal coliform in the applied biosolids, if they are similar to those measured in biosolids samples collected in conjunction with previous fecal coliform TMDLs in Virginia, were probably orders of magnitude less than the allowable 1,995,262 cfu/gram; and (4) the reported biosolids applications rates were considerably lower than the allowable 15 dry tons/acre. (5) biosolids have stringent land application regulations (VDHBUR 1997) to help insure that constituents such as fecal coliform do not reach surface waters. Because of all of these facts, biosolids are considered an insignificant source of fecal coliform in the Naked Creek watershed.

4.1.2. Failing Septic Systems

Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed that no die-off occurred once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. There are no sewered households in the watershed. Households were located using E-911 digital data, (see Glossary) (Augusta and Rockingham Co. Planning Dept., 2001). Each unsewered household was classified into one of three age categories (pre-1971, 1971-1984, and post-1984) based on USGS 7.5-min. topographic maps which were initially created using 1969 photographs and were photo-revised in 1984.

Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1971, 1971-1984, and post-1984 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located just north of the study area and Linville Creek), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (Bankson, 2000).

Daily total fecal coliform load to the land from a failing septic system was determined by multiplying the average occupancy rate for the watershed (2.4 persons, 1990 Census) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1977). Hence, the total fecal coliform loading to the land from a failing septic system was 4.68×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.3.

4.1.3. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1971 and 1971-1984 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, there were 4 straight pipes estimated to be in the watershed.

4.1.4. Pets

Assuming one pet per household, there are 587 pets in Naked Creek watershed. A pet produces 0.45×10^9 cfu/day (Weiskel et al., 1996). The pet population distribution among the sub-watersheds is listed in Table 4.3. Pet waste is generated in the rural residential and urban residential land use types. Fecal coliform loading to streams from pet waste can result from surface runoff transporting fecal coliform from residential areas.

Table 4.3. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Naked Creek watershed.

Subwatershed	Unsewered houses in each age category (no.)			Failing septic systems (no.)	Pet population[a]
	Pre-1971	1971-1984	Post-1984		
B28-01	8	19	14	7.4	43
B28-02	19	8	24	9.9	51
B28-03	50	37	54	29	141
B28-04	37	34	43	22.9	114
B28-05,06	27	18	24	15.1	70
B28-07	7	1	14	3.4	22
B28-08	14	7	12	7.4	34
B28-09	14	13	10	8.5	37
B28-10	23	20	32	14.2	75
Total	199	157	227	117.8	587

[a] Assumed an average of one pet per household and 4 households were estimated to have straight pipes to obtain a total number of households of 587.

4.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop and hay land.

4.2.1. Distribution of Dairy and Beef Cattle in the Naked Creek watershed

There are four dairy farms in the watershed with an average herd size of approximately 158 cows (milk cows and dry cows), based on information obtained from area farmers. The total number of milk and dry cows was estimated at 315. Based on discussion with the farmers and the SWCD personnel, of the dairy cattle population in the watershed, 42% of the cattle are milk cows, 8% are dry cows, and 50% are heifers, resulting in a total of 630 dairy cattle for the watershed (Table 4.2). The dairy cattle population was distributed among the sub-watersheds based on the location of dairy farms and average herd size (Table 4.4). Table 4.4 shows the number of dairy operations for each sub-watershed. There were no dairy operations with large loafing lots in the watershed.

Table 4.4. Distribution of dairy cattle, dairy operations and beef cattle among sub-watersheds.

Sub-watershed	Dairy cattle	No. of dairy operations	Beef cattle
B28-01	0	0	135
B28-02	0	0	206
B28-03	0	0	575
B28-04	200	1	477
B28-05,06	310	2	597
B28-07	0	0	270
B28-08	0	0	439
B28-09	0	0	279
B28-10	120	1	562
Total	630	4	3,540

Beef cattle in the watershed included cow/calf and feeder operations. The beef cattle population (3,540 cattle) in the watershed was estimated based on local knowledge. The following procedure was used to estimate beef population by sub-watershed (Table 4.4).

1. Based on local knowledge of the watersheds, it was assumed that pastures 1 and 2 had stocking ratios of 1 and 2 respectively, i.e., pasture 2 was stocked with twice the number of animals per acre than pasture 1. Accordingly, relative stocking densities (RSDs) for Pastures 1 and 2 were 0.33 (1/3) and 0.67 (2/3), respectively.

2. Fraction of beef cattle in each pasture category was calculated as follows.
   Fraction of beef cattle in pasture 1 =
   (P1 x RSD1) /((P1 x RSD1) + (P2 x RSD2)) [4.1a]
   Fraction of beef cattle in pasture 2 =
   (P2 x RSD2) /((P1 x RSD1) + (P2 x RSD2)) [4.1b]
   where, P1 and P2 = acreages under pastures 1 and 2, respectively. As mentioned earlier, RSD1 = 0.33 and RSD2 = 0.67 are relative stocking densities in pastures 1 and 2, respectively.

3. Number of beef cattle in each pasture category was calculated by multiplying the acreage by the fraction of beef cattle in that category. Stocking density for

each pasture category was obtained by dividing the number of beef cattle in that pasture category by its respective acreage. Beef cattle stocking densities for pastures 1 and 2 were 0.76 and 0.24 beef cattle/acre, respectively.

4. For each sub-watershed, pasture 1 acreage was multiplied by pasture 1 stocking density to calculate number of beef cattle in pasture 1. Similarly, beef cattle numbers were calculated for pasture 2. Beef cattle population in the sub-watershed was obtained by summing the cattle population for the two pasture categories.

Depending on the time of year and type of cattle (i.e., milk cow versus heifer), cattle spend varying amounts of time in different land use types (i.e., confinement versus pasture). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (thus their manure) among different land use types and in the stream.

a) Cows are confined according to the schedule given in Table 4.5.

b) When the milk cows are not confined, they 100% of the time on pasture. All other dairy (dry cows and heifers) and beef cattle are on pastures when not in confinement.

c) Pasture 2 (unimproved pasture/grazed woodlands) stocks twice as many cows per unit area as pasture 1 (improved pasture/hayland).

d) Cows on pastures that are contiguous to streams (1,609 acres for all pasture categories, Table 4.6), have stream access.

e) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.5). Cows spend more time in the stream during the three summer months, among other things, to protect their hooves from hornflies.

f) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited in pastures.

Table 4.5. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)		Time spent in the stream (hours/day)[a]
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	30%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

[a] Time spent in and around the stream by cows that have stream access.

Table 4.6. Pasture acreages contiguous to stream.

Sub-watershed	Pasture 1		Pasture 2	
	Acres	%[a]	Acres	%[a]
B28-01	195.3	58%	1.7	5%
B28-02	54.1	33%	108.6	48%
B28-03	859.8	60%	11.3	8%
B28-04	214.9	24%	29.4	11%
B28-05,06	776.7	49%	4.0	4%
B28-07	473.7	60%	0.1	1%
B28-08	534.4	49%	6.5	6%
B28-09	362.4	59%	15.2	14%
B28-10	121.3	10%	11.5	5%
Total	3592.6	44%	188.4	15%

[a] Percent of pasture area contiguous to stream to the total pasture area of that type in that sub-watershed.

A sample calculation for determining the dairy cattle numbers to different land use types and stream in sub-watershed B28-10 is shown in Appendix B. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.7 for dairy cattle and in Table 4.8 for beef cattle.

Table 4.7. Distribution of the dairy cattle[a] population.

Months	Confined	Pasture1	Pasture2	Stream[b]
January	344.6	220.2	64.6	0.6
February	344.6	220.2	64.6	0.6
March	105.8	404	118.8	1.4
April	79.4	424	124.6	2
May	79.4	423.2	124.4	3
June	79.4	419.8	123.8	7
July	79.4	419.8	123.8	7
August	79.4	419.8	123.8	7
September	79.4	423.2	124.4	3
October	79.4	424	124.6	2
November	105.8	404	118.8	1.4
December	344.6	220.2	64.6	0.6

[a] Includes milk cows, dry cows, and heifers.

[b] No. of dairy cattle defecating in stream.

Table 4.8. Distribution of the beef cattle population.

Months	Confined	Pasture1	Pasture2	Stream[a]
January	1416.0	1628.0	491.1	5.0
February	1416.0	1628.0	491.1	5.0
March	0.0	2710.0	817.6	12.5
April	0.0	2706.7	816.7	16.6
May	0.0	2700.0	815.0	24.9
June	0.0	2673.6	808.2	58.2
July	0.0	2673.6	808.2	58.2
August	0.0	2673.6	808.2	58.2
September	0.0	2700.0	815.0	24.9
October	0.0	2706.7	816.7	16.6
November	0.0	2710.0	817.6	12.5
December	1416.0	1628.0	491.1	5.0

[a] No. of beef cattle defecating in stream.

4.2.2. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.7) and beef cattle (Table 4.8) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 608,571 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 8.60×10^{11} cfu. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that mainly dissolved fecal coliform bacteria are transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.3. Direct Manure Deposition on Pastures

Dairy (Table 4.7) and beef (Table 4.8) cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture 1 and pasture 2 have average annual cattle manure loadings of 7,515 and 14,990 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from cattle on a daily basis, averaged over the year, are 1.05×10^{10} cfu/ac-day and 2.09×10^{10} cfu/ac-day for pastures 1 and 2, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.2.4. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure/day (ASAE, 1998). Based on the monthly confinement schedule (Table 4.5) and the number of milk cows (Section 4.2.1), annual liquid dairy manure production in the watershed is 5.6 million gallons. Based on per capita fecal coliform production of milk cows, fresh liquid dairy manure contains 1.18×10^9 cfu/gal. It was assumed that all liquid dairy manure produced in a sub-watershed was applied within that sub-watershed. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture 1 land use categories (VADCR, 1999), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 34.7 acres (5.25%) of cropland and 31.7 acres (<1%) of pasture 1. Since there was insufficient liquid dairy manure for cropland and pasture 1, no liquid dairy manure was applied to pasture 2.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (VADCR, 1999). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. During June through September, liquid manure is surface-applied to pasture 1. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (VADCR, 1999) is given in Table 4.9. Dry cows and heifers were assumed to produce only solid manure.

Table 4.9. Schedule of cattle and poultry waste application in Naked Creek watershed.

Month	Liquid manure applied (%)a	Solid manure or poultry litter applied (%)[a]
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

[a] As percent of annual production.

4.2.5. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.10. As in the case of liquid manure, it was assumed that all solid manure produced within a sub-watershed is applied to that sub-watershed. Amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.4) and their confinement schedules (Table 4.5). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.10). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 4.10). Dry cows and heifers account for 8 and 42% of the total dairy cattle population in each sub-watershed, respectively.

Table 4.10. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)	Weighted average fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	25	1,400[a]	115.0[b]	174[c]	302
Heifer	315	640[d]	40.7[a]	226[c]	
Beef	3,540	1,000[e]	60.0[f]	430[c]	

[a] Source: ASAE (1998)
[b] Source: VADCR (1995)
[c] Based on per capita fecal coliform production per day (Table 4.2) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e] Based on input from local producers
[f] Source: MWPS (1993)

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture 1, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. During June through September, all solid manure is applied to pasture 1. The method of application of solid manure to cropland or pasture 1 is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.9. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid manure was applied to 252 acres (38%) of the cropland and 81 acres (1%) of pasture 1. Since there was insufficient solid manure for cropland and pasture 1, solid manure was not applied to pasture 2.

4.3. Poultry

The poultry population (Table 4.2) was estimated based on discussions with local producers and nutrient management specialists. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied (**Table 4.11**). It is not known which poultry litter (broiler or broiler breeder or turkey) is applied to a land use. Hence, a weighted average fecal coliform concentration was estimated for poultry litter based on relative proportions of litter from all poultry types and their respective fecal coliform contents (**Table 4.11**).

Since poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. Poultry litter is applied at the rate of 3 tons/ac-year to cropland first, the remaining litter is applied to pasture 1. After application to cropland and pasture 1, the remaining litter is applied to pasture 2 at the rate of 1.5 tons/ac-year. Method of poultry litter application to cropland and pastures is assumed to be identical to the method of cattle manure application. Application schedule of poultry litter is given in Table 4.9. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 451 acres (68%) of cropland and 1,286 acres (16%) of pasture 1. Pasture 2 did not receive any poultry litter since there was insufficient poultry litter to apply to the entire cropland and pasture 1 areas.

Table 4.11. Estimated daily litter production, litter fecal coliform content for individual poultry types, and weighted average fecal coliform content.

Poultry Type	Typical Weight (lb)[a]	Production cycles(per year)[b]	Occupancy factor[c]	Litter produced per bird		Fecal coliform content ($\times 10^9$ cfu/lb)[f]	Weighted average fecal coliform content ($\times 10^9$ cfu/lb)
				(lb/cycle)[d]	(lb/day)[e]		
Broiler Breeder[g]	4	1.09	0.96	30.0	0.09	1.46	0.86
Broiler	2	6	0.79	2.6	0.04	1.65	
Turkey	15	5	0.87	18.0	0.25	0.33	

[a] Source: ASAE (1998)

[b] Based on information from VADCR and producers

[c] Fraction of time when the poultry house is occupied; layer – 46 weeks/48 weeks; broiler – 48 days/61 days; turkey (5 cycles) – 45 weeks/52 weeks

[d] Source: VADCR (1999)

[e] Litter produced per bird per day is equal to the product of production cycles per year and litter produced per cycle divided by number of days in a year.

[f] Fecal content in litter is equal to fecal coliform produced per day per bird (Table 4.2) multiplied by the occupancy factor, divided by the litter produced per day per bird.

[g] Broiler Breeders were considered equivalent to Layers.

Given that poultry litter is lighter to transport (due to its lower water content) than cattle manure, poultry litter produced within the watershed is assumed to be applied throughout the watershed irrespective of the sub-watershed in which it is produced. Since there is sufficient acreage of appropriate land uses within the watershed for land application, no poultry litter is exported from the watershed. Poultry litter was allocated to sub-watersheds as a fraction of the total amount produced within the watershed as follows:

$$PL_i = \frac{((CL_i + P1_i) \times AF_1) + (P2_i \times AF_2)}{\sum_{i=1}^{N} \{((CL_i + P1_i) \times AF_1) + (P2_i \times AF_2)\}} \qquad [4.2]$$

where,

N = number of subwatersheds in the watershed (9);

Cli = Cropland acreage in sub-watershed i;

$P1_i$ = Pasture 1 acreage in sub-watershed i;

$P2_i$ = Pasture 2 acreage in sub-watershed i;

AF_1 = Application factor, is one for cropland and pasture 1; and

AF_2 = Application factor, considered 1/2 for pasture 2 with one-half application rate as compared to cropland and pasture 1.

Using Equation [4.2], poultry litter amounts were assigned to individual sub-watersheds as percent of total poultry litter produced within the watershed (Table 4.12).

Table 4.12. Distribution of poultry litter among the sub-watersheds.

Sub-watershed	Poultry litter[a] (%)
B28-01	48%
B28-02	8%
B28-03	14%
B28-04	18%
B28-05,06	7%
B28-07	<1%
B28-08	5%
B28-09	<1%
B28-10	<1%
Total	100%

[a] Percent of total assigned to (but not necessarily produced in) the subwatershed

4.4. Sheep and Goats

The sheep and goat populations (Table 4.2) were estimated based on discussions with local producers and nutrient management specialists. The sheep herd was composed of lambs and ewes. The lamb population was expressed in equivalent sheep numbers. The equivalent sheep population calculated for lambs was based on the assumption that the average weight of a lamb is half of the weight of a sheep. The lamb population for the Naked Creek watershed was estimated to be 1,380. The equivalent sheep population for the lambs was 690. A similar approach was used for goats. The equivalent number of sheep for goats was calculated based on the ratio of manure production. It was assumed that the average weight for a goat and a sheep were 140 lb and 60 lb, respectively (ASAE, 1998). The equivalent number of goats of 379 was calculated as the ratio of the goat weight to the sheep weight (140/60) times the number of goats in the watershed (170). The total number of sheep for the Naked Creek watershed was the sum of the number of ewes (690), equivalent number of lambs (690), and the equivalent number of goats (397), for a total of 1,777. The sheep were kept on pastures 1 and 2. The relative stocking density for sheep was estimated to be 0.4 for pasture 1 and 0.6 for pasture 2 based on discussions with local producers. Sheep (goats and lambs) were only located in sub-watersheds B28-03 and B28-08. The equivalent sheep population in B28-03 and B28-08 were 670 and 1,107, respectively. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was added to the loads applied to pastures 1 and 2.

Pasture 1 and pasture 2 have average annual sheep manure loadings of 247 and 3,738 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from sheep on a daily basis averaged over the year are 3.38×10^6 cfu/ac-day and 51.17×10^6 cfu/ac-day for pastures 1 and 2, respectively.

4.5. Horses

Horse populations for the Naked Creek watershed were obtained through local knowledge of the SWCD. The total horse population was estimated to be 375. Significant horse populations were located in sub-watersheds B28-3, B28-4, and B28-5,6. The distribution of horse population among the sub-watersheds is listed in Table 4.13. Horses are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to pastures 1 and 2. The relative stocking ratios for horse among pastures 1 and 2 were 0.94 and 0.06, respectively. Pasture 1 and pasture 2 have average annual horse manure loadings of 790 and 386 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from sheep on a daily basis averaged over the year are 1.04×10^5 cfu/ac-day and 0.51×10^5 cfu/ac-day for pastures 1 and 2, respectively.

Table 4.13. Horse populations among Naked Creek sub-watersheds.

Sub-watershed	Horse Population
B28-1	0
B28-2	0
B28-3	56
B28-4	206
B28-5,6	113
B28-7	0
B28-8	0
B28-9	0
B28-10	0
Total	375

4.6. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.2) along with preferred habitat and habitat area (Table 4.14).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon their habitat (Table 4.16). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on pasture and forest acreage in the sub-watershed and as a fraction of pasture plus forest area in the entire watershed. Also, further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 ft buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among subwatersheds is given in Table 4.15.

Table 4.14. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	14,674	0.047	1%
Raccoon	600 ft buffer around streams and impoundments	5,050	0.07	10%
Muskrat	66 ft buffer around streams and impoundments	457	2.75	25%
Beaver[a]	300 ft buffer streams and impoundments	3,064	0.015	50%
Geese[b]	66 ft buffer around streams and impoundments	457	Not Applicable [b]	25%
Wood Duck[b]	66 ft buffer around streams and impoundments	457	Not Applicable [b]	25%
Wild Turkey	Entire Watershed	14,674	0.0098	1%

[a] Stromayer (1999)

[b] Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, Va.)

Table 4.15. Distribution of wildlife among sub-watersheds.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
B28-01	29	15	54	1	1	2	6
B28-02	38	22	86	2	2	3	8
B28-03	115	45	192	5	5	7	24
B28-04	88	47	157	4	4	6	18
B28-05,06	129	85	319	9	9	11	27
B28-07	67	37	113	3	3	4	14
B28-08	74	51	163	5	5	6	16
B28-09	44	22	94	2	2	3	9
B28-10	105	31	94	3	3	3	22
Total	689	355	1,272	34	34	45	144

4.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4.16. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.16.

From Table 4.16, it is clear that nonpoint source loadings to the land surface are over 150 times larger than direct nonpoint source loadings to the streams, with pastures receiving more than 97% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, cultural activities (application time and method), type of waste (Solid versus liquid manure) and proximity to streams also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model in estimating fecal coliform loads to the receiving waters, as described in Chapter 5, considers these factors.

Table 4.16. Annual fecal coliform loadings to the stream and the various land use categories in the Naked Creek watershed.

Source	Fecal coliform loading ($\times 10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	31.3	0.6%
Wildlife in stream	1.2	<0.1%
Straight pipes	0.6	<0.1%
Loading to land surfaces		
Cropland	51.6	1.0%
Pasture 1	3,509	69.2%
Pasture 2	1,422	28.0%
Residential	55.0	1.1%
Forest	2.8	0.1%
Total	5,073	

[a] Includes loads applied to both High and Low Density Residential and Farmstead.

CHAPTER 5: MODELING PROCESS FOR TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling process, input data requirements, model calibration procedure and results, and model validation results are discussed.

5.1. Model Description

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (WinHSPF) (Duda et al., 2001) was used to model fecal coliform transport and fate in the Naked Creek watershed. The BASINS interface (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 3.0 (USEPA, 2001) was used to facilitate use of HSPF. Specifically, the WinHSPF interface within BASINS provides pre- and post-processing support for HSPF. The ArcView 3.0a or 3.1 GIS provides the integrating framework for BASINS and allows the display and analysis of landscape information.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda et al., 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules, HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

5.2. Selection of Sub-watersheds

Naked Creek is a moderately sized watershed (14,674 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into ten sub-watersheds as shown in Figure 3.1. The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Since loadings of fecal coliform are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The sub-watershed NC-06 was delineated to preserve the stream network of the watershed and results in a much smaller sub-watershed relative to the other sub-watershed. When calculating the fecal loads, the sub-watershed NC-06 was combined with NC-05. The loads calculated for the combined sub-watershed of NC-05 and NC-06 were applied to sub-watershed NC-05 in the simulations.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Naked Creek watershed are discussed below.

5.3.1. Climatological Data

Weather data needed to conduct the model simulations were taken from a weather data set developed for a neighboring watershed (Christians Creek) and updated using precipitation data from two other neighboring watersheds. The weather data set developed by the USGS for the Christians Creek fecal coliform TMDL (USGS, 2002) covered the period from January, 1986 through December 1998. Christians and Naked Creek are in close proximity to one another and Christians Creek is east of Naked Creek. The data for this period came from several National Weather Service (NWS) monitoring stations accessed from the National Climatic Data Center (NCDC) (USGS, 2002). The majority of the hourly precipitation data was taken from the Staunton Sewage Treatment Plant, which is south west of the Naked Creek watershed. Missing data was filled in using precipitation data from several other NWS stations near the Christians Creek watershed (USGS, 2002). The other metrological data needed to conduct the simulations, such as potential evaporation, solar radiation, air temperature, etc., were taken from NWS stations near the Christians Creek watershed (USGS, 2002).

Precipitation data from two other neighboring watersheds (Long Glade and Mossy Creek) were used to extend the period of the weather data to December of 2000. The remaining weather parameters (i.e. evaporation, solar radiation, etc.) in the data set for the period of 1999 and 2000 were populated using the data from the previous two years (1997 and 1998). The Long Glade watershed is adjacent to the Naked Creek watershed and Mossy Creek is immediately adjacent to Long Glade. Precipitation data from Mossy Creek and Long Glade watersheds were used to extend the data set developed by USGS. The period of the weather data set was extended to cover the period of the water quality data available for Naked Creek, which extended to December of 2000. This allowed for a longer calibration period for the water quality component of the simulations. The precipitation data for Mossy Creek and Long Glade is being collected as a monitoring project conducted by the Biological Systems Engineering Department, Virginia Tech (Mostaghimi et al., 2001).

5.3.2. Hydrology Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land use category for each sub-watershed. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Duda et al., 2001). These parameters were estimated by surveying representative channel cross-sections in each sub-watershed. Information on stream geometry in each sub-watershed is presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in BASINS Version 3.0 User's Manual 3.0 (USEPA, 2001). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the BASINS Version 3.0 User's Manual (USEPA, 2001). Runoff estimated by the model is also an input to the water quality components. Values for the parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used.

Table 5.1. Stream characteristics of the Naked Creek watershed.

Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
B28-01	0.98	12.5	1.0	0.006
B28-02	1.67	4.5	0.6	0.003
B28-03	3.74	4.0	0.4	0.002
B28-04	1.87	6.0	1.0	0.003
B28-05	3.54	4.5	0.1	0.002
B28-06	0.76	5.0	0.5	0.008
B28-07	1.59	4.0	0.1	0.004
B28-08	1.91	4.5	0.3	0.003
B28-09	1.80	5.0	0.8	0.003
B28-10	1.28	3.0	0.25	0.004

5.4. Land use

Virginia DCR identified twelve land use types in the watershed. As described in Chapter 3, the twelve land use types were consolidated into seven categories based on hydrologic and waste application/production characteristics (Table 3.1). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Land use data were used to select several hydrology and water quality parameters for the simulations.

5.5. Accounting for Pollutant Sources

5.5.1. Overview

There were two VADEQ permitted fecal coliform point sources in the Naked Creek watershed. Fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. There were two point sources permitted to discharge fecal coliform in the watershed and these were incorporated into the simulations at the locations on the stream designated in the permit.

The nonpoint source loading was applied as fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated during manure storage, while on the land, and in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

5.5.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using a first order die-off equation of the form:

$$C_t = C_0 10^{-Kt} \quad [5.1]$$

where: C_t = concentration or load at time t

C_0 = starting concentration or load

K = decay rate (day^{-1}), and

t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Naked Creek watershed (Table 5.2).

Table 5.2. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971)a
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973)a
Poultry litter	Soil surface	0.035	Giddens et al. (1973)
		0.342	Crane et al. (1980)

[a] Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Since the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.

- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day-1 was used assuming that a majority of manure piles are not covered.

- Poultry waste in pile/house: Since no decay rates were found for poultry waste in storage, a decay rate of 0.035 day^{-1} was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day^{-1} (Table 5.2) since fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix C. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. By multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure), the amount of fecal coliform available for application to land per year is estimated. Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} (USEPA, 1985) was used.

5.5.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in Naked Creek watershed are presented in Appendix E. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from cattle and wildlife, pastures receive applications of liquid dairy manure and solid manure as described in Chapter 4. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.

3. Low Density Residential and Farmstead: Fecal coliform loading on rural residential and Farmstead land use came from failing septic systems, wildlife and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential land use areas.

4. High-Density Residential: The high density residential contained much of the Commercial/Industrial areas. Fecal coliform loading to the high density residential land use was assumed to be a constant 10.3×10^6 cfu/day (USEPA, 2000)

5. Forest: Wildlife not defecating in streams, cropland, and pastures provided fecal coliform loading to the forested land use. Fecal coliform, except for the percentage considered as direct load to the stream, was applied uniformly over the forest areas.

5.5.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences that might be present. Also, contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 15 cfu/100mL. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapters 4.

5.6. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component and the calibration results of the water quality component are presented.

5.6.1. Hydrology

For the hydrologic component of the HSPF calibration, observed values for daily stream flow are required. No quantitative stream flow observations were available for Naked Creek. Calibrated input data sets were developed for a watershed near Naked Creek. The calibrated hydrologic input parameters developed for Linville Creek were used for the Naked Creek simulations. The calibration procedure and a discussion of the results are available in Mostaghimi et al. (1999) and Brannan et al. (2000). The USGS station monitoring Linville Creek is located near Broadway, Virginia (Station Number 01632982). The drainage area monitored at the station is 45.5 square miles (29,120 acres) and the available period of record is August 1985 through September 1998 (approximately 13 years). There was also data available for the Christians Creek watershed from a USGS station near Fisherville, Virginia (Station Number 01624800) that monitors a drainage area of 70.1 square miles (44,864 acres). The Christains Creek watershed was not used for the Naked Creek watershed calibration because it was judged too large and because of differences in watershed shape and land use.

The location of the Linville Creek watershed relative to Naked Creek is shown in Figure 5.1. The hydrology calibration was performed using the Linville Creek data. This period of record ensured that a representative time period that included both wet and dry periods was included in the calibration period. Also, the period of record from Linville Creek provided sufficient data to conduct validation runs of the same length as the calibration runs. Furthermore, similarity in land use characteristics between the Naked Creek and Linville Creek watersheds (Table 5.3) indicated the appropriateness of using the Linville Creek watershed for calibrating the HSPF model. The calibration period selected for the Linville Creek data was September 1, 1991 to January 18, 1996, and the validation period was September 1, 1986 to August 31, 1990.

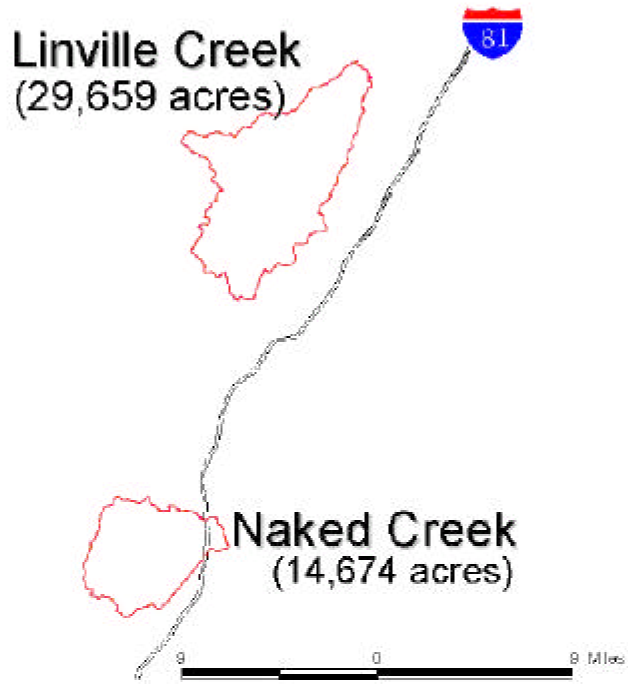

Figure 5.1. Location of calibration and validation watersheds relative to the Naked Creek watershed.

Table 5.3. Comparison of land use distribution between Naked Creek and Linville Creek watersheds.

Land use	Naked Creek	Linville Creek
Cropland	4.5%	21.4%
Pasture	64%	49.4%
Forest	30%	15.7%
Residential	0.5%	8.3%

The calibration of the HSPF hydrology parameters resulted in simulated flows that accurately matched the observed data for Linville Creek. A comparison of the simulated and observed stream flow data is given in Table 5.4 for the calibration period of September 1, 1991 to March 1, 1996 for Linville Creek. There was very good agreement between the observed and simulated stream flow indicating that the model represented the hydrologic characteristics of the watershed very well. In Figure 5.2, the simulated and observed stream flow for a smaller period within the calibration period is shown. The simulated data follow the pattern of the observed data very well. The model closely simulates both low flows and storm peaks.

Table 5.4. Linville Creek calibration simulation results (September 1, 1991 to March 1, 1996).

Parameter	Simulated (inches)	Observed (inches)	% Percent Error
Total stream flow	54.9	55.2	-0.5%
Summer[a] stream flow	7.6	7.5	0.01%
Winter[b] stream flow	20.2	21.5	-6.0%

[a] June – August

[b] December – February

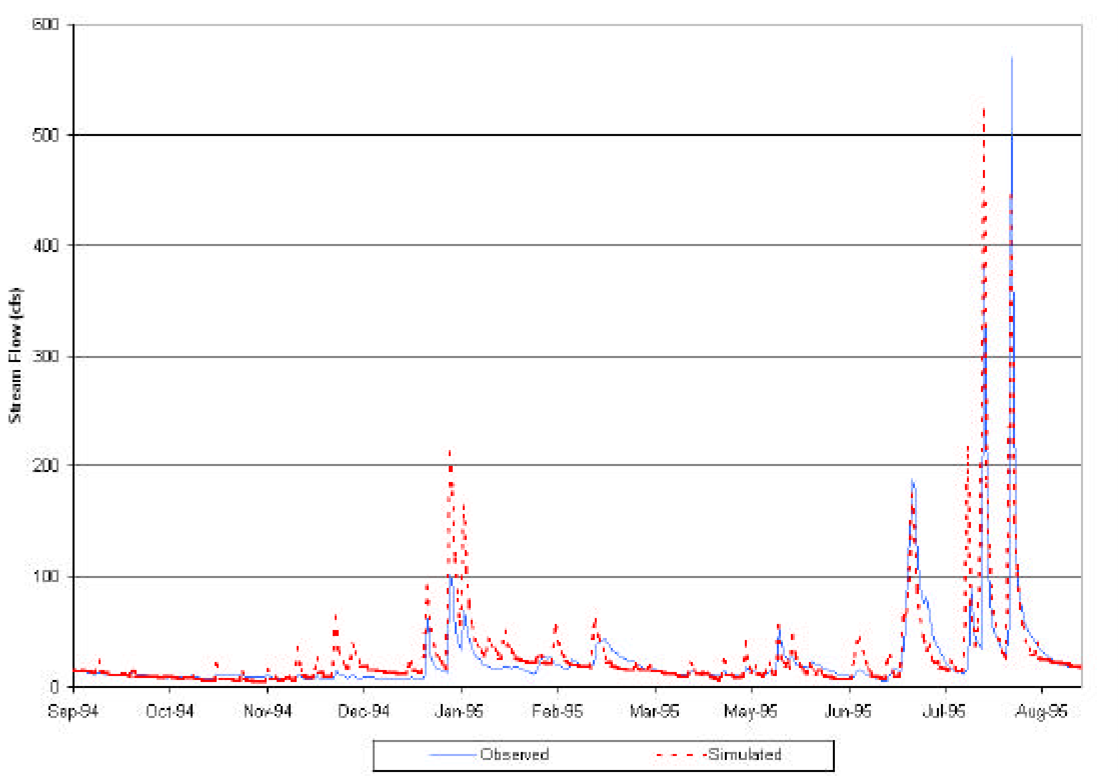

Figure 5.2. Simulated and observed stream flow for Linville Creek for a portion of the calibration period (Sept. 1, 1994 to August 31, 1995).

The calibrated data set was then used in the model to predict runoff for a different time period for Linville Creek to provide a basis for evaluating the appropriateness of the calibrated parameters. A comparison of the simulated and observed stream flow data is given in Table 5.5 for the validation period of September 1, 1986 to August 31, 1991 for Linville Creek.

Table 5.5. Linville Creek validation simulation results (September 1, 1986 to August 31, 1991).

Parameter	Simulated (inches)	Observed (inches)	% Percent Error
Total stream flow	51.4	48.0	7.1%
Summer[a] stream flow	7.5	6.5	15.4%
Winter[b] stream flow	15.6	14.4	8.3%

[a] June – August

[b] December – February

There was very good agreement between the observed and simulated stream flow, indicating that the calibrated parameters represent the characteristics of the watershed reasonably well for time periods in addition to the calibration period. The simulated and observed stream flow for a smaller period within the validation period is shown (Figure 5.3). The simulated data follow the pattern of the observed data well.

In general, the validation results from Linville indicate that the calibrated model characterizes the hydrologic processes of the region well. Therefore, the calibrated parameters were assumed to provide a good first estimate of parameters required to simulate the hydrology of the Naked Creek watershed for TMDL development purposes. Due to lack of stream flow data from Naked Creek, a detailed analysis of the model's performance for this watershed was not possible.

The pathway that water takes to reach the stream is extremely important when simulating fecal coliform. The HSPF model considers three pathways that water from precipitation falling on the land surface can reach the stream. These pathways are surface flow, interflow or shallow subsurface flow, and active groundwater flow. The main pathway fecal coliform can reach the stream, besides point sources and direct deposited nonpoint sources, is via surface flow. Therefore, the partition of total flow among surface flow (SURO), interflow

(IFWO), and active groundwater (AGWO) is very important. The partitioning of flow among the three pathways was investigated for the Naked Creek simulations. The portion of the total flow among the three pathways is given in Table 5.6. Based on our experience monitoring and modeling other watersheds near the Naked Creek watershed, the partitioning of flow among the three pathways is acceptable.

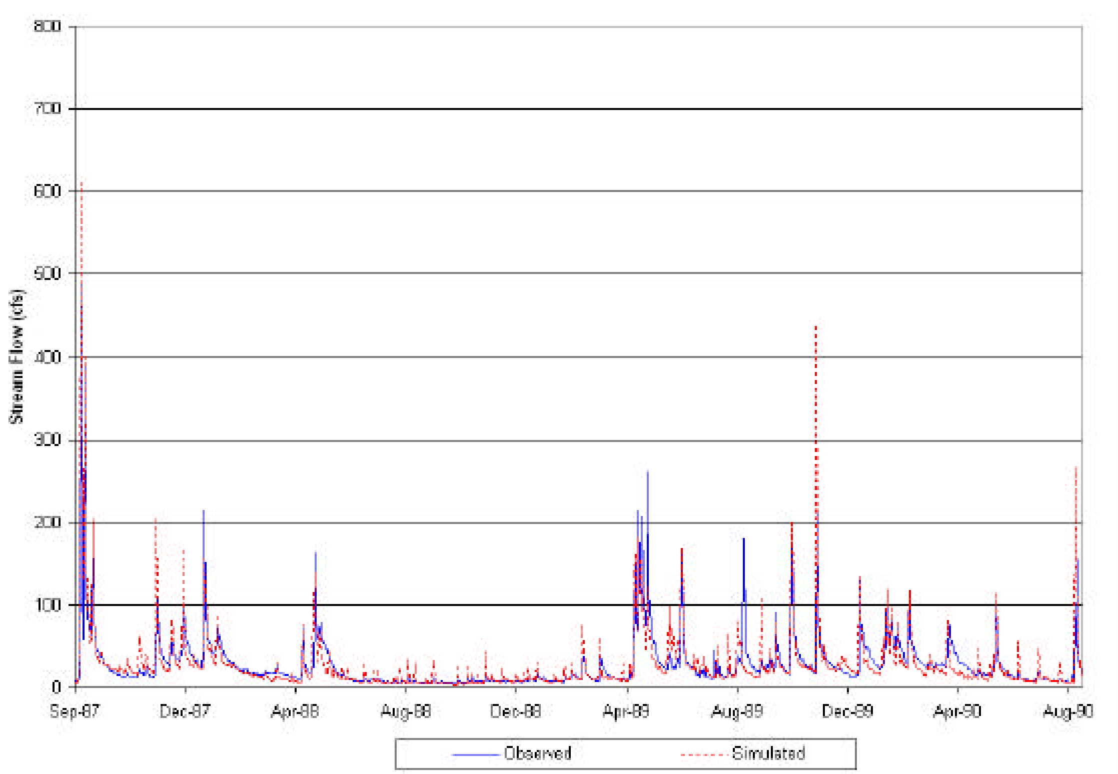

Figure 5.3. Simulated and observed average daily stream flow for Linville Creek for a portion of the validation period (September 1, 1987 to August 31, 1990).

Table 5.6. Partition of flow among surface flow, interflow, and groundwater flow for the period of July 1991 to December 1997.

	Surface Flow (%)	InterFlow (%)	Groundwater Flow (%)
Percent of Total Flow	22.09%	24.15%	53.76%
Percent of Precipitation	9.83%	10.75%	23.93%

5.6.2. Fecal coliform calibration

Procedure

The water quality component of HSPF was calibrated using ninety-two fecal coliform samples for the Naked Creek watershed that were collected by VADEQ. The VADEQ samples covered the period from July 1991 to December 2000. A cap of 8,000 cfu/100 mL was imposed on the observed fecal coliform concentrations because of VADEQ laboratory procedures. Therefore, the simulated concentrations should have values close to or greater than these capped values. The accuracy of the simulations was measured visually using graphs of simulated and observed values.

Results

There was generally good agreement among the simulated and observed fecal coliform concentrations. The daily average of the simulated concentrations and the observed fecal coliform concentration are shown in Figure 5.4. The overall pattern of the observed concentrations is represented in the simulated concentrations. For instance, simulated concentrations match the low concentrations observed during the period of November 1993 through April 1994. This was true for other periods when low concentrations were observed. Also, the simulated concentrations increased during the summer and early fall when the higher concentrations observed generally occurred. Simulated fecal coliform concentrations were under-predicted on a few days (February and May of 1995) and were over-predicted on a few others (June, July and September 1999). Efforts were made to improve the agreement between the simulated and observed concentrations by adjusting the input to the model and investigating if there were errors or misrepresentations in the precipitation data to no avail. In general, the agreement between the simulated and observed concentrations was good and the model represents the processes influencing the concentration of fecal coliform in Naked Creek well.

The pollutant transport and water quality input parameters used in the simulation of Naked Creek are listed in Table 5.7. The parameters for the PQUAL, IQUAL, and the GQUAL modules of HSPF are given in Table 5.7 along with an explanation of the value and the ranges for the parameters.

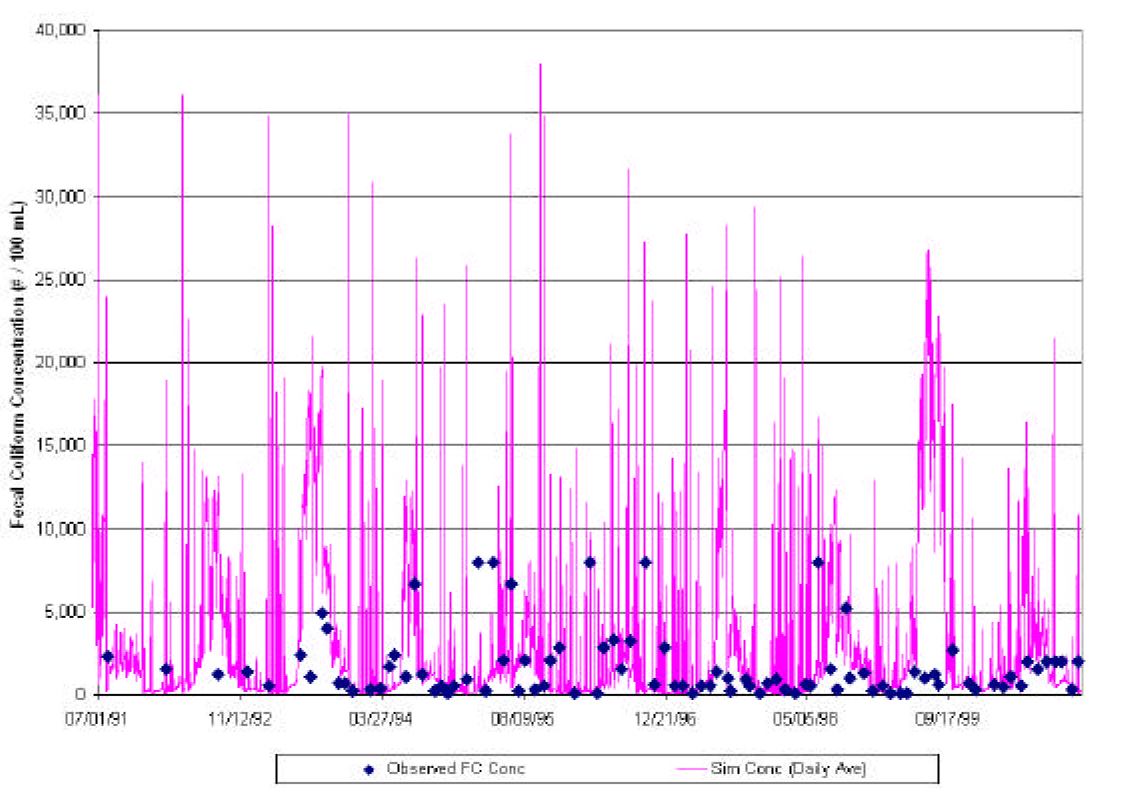

Figure 5.4. Naked Creek fecal coliform calibration for existing conditions.

Table 5.7. Input parameters used in HSPF simulations for Naked Creek.

Parameter	Definition	Units	RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF...
			TYPICAL		POSSIBLE				
			MIN	MAX	MIN	MAX			
PERLAND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0.0, 1.0	1.0 forest, 0.0 other	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	14.1	6-7[1]	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.16	0.05-0.08[1]	Soil and cover conditions
LSUR	Length of overland flow	feet	200	500	100	700	300	300	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.03-0.10[1]	Topography
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.98	0.98	Calibrate
PWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.1	0.19	Geology
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0.02	0.05	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	0	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	monthly[1]	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	1.128	0.2-0.7[1]	Soil properties
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.2-0.25[1]	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.75	1.1	Soils, topography, land use
IRC	Interfiow recession parameter	none	0.5	0.7	0.3	0.85	0.5	0.6	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	monthly	monthly[1]	Vegetation
QUAL-INPUT									
ACQOP	Rate of accumulation of constituent	#/day						monthly[1]	Land use
SQOLIM	Maximum accumulation of constituent	#						9 x ACQOP	Land use
WSQOP	Wash-off rate	in/hr						1.5	Land use
IOQC	Constituent conc. in interflow	#/ft3						4248	Land use

[1] Varies with land use

Table 5.7. Input parameters used in HSPF simulations for Naked Creek. (Continued)

Parameter	Definition	Units	RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF…
			TYPICAL		POSSIBLE				
			MIN	MAX	MIN	MAX			
PERLIND									
AOQC	Constituent conc. in active groundwater	#/ft3						4248	Land use
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	feet	200	500	100	700	300	220-250[1]	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.03-0.07[1]	Topography
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.10	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.065	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
IQUAL									
ACQOP	Rate of accumulation of constituent	#/day						1.0E+07	Land use
SQOLIM	Maximum accumulation of constituent	#						9.0E+07	Land use
WSQOP	Wash-off rate	in/hr						1.8	Land use
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing							0.5	
GQUAL									
FSTDEC	First order decay rate of the constituent	1/day						1.15	
THFST	Temperature correction coeff. for FSTDEC							1.05	

[1] Varies with land use

CHAPTER 6: LOAD ALLOCATIONS

6.1. Background

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The objective of the TMDL for Naked Creek was to determine what reductions in fecal coliform loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standard for fecal coliform used in the development of the TMDL was 200 cfu/100mL (30-day geometric mean). The TMDL considers all sources contributing fecal coliform to Naked Creek. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [6.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (EPA, 1991). For the Naked Creek TMDL, a MOS of 5% was incorporated explicitly in the TMDL equation, in effect reducing the target fecal coliform concentration (30-day geometric mean) from 200 cfu/100mL to 190 cfu/100mL.

The time period selected for the load allocation study was January 1, 1994 to December 31, 1997, a portion of the period for which observed data were available. This period was selected because it covers the period in which water quality violations were observed and it incorporates average rainfall, low rainfall, and high rainfall years (Table 6.1), and this climatic record results in a wide range of hydrologic events including both low and high flow conditions.

The 30-day geometric mean values used in this report are running 30-day geometric means. Since HSPF was operated with a one-hour time step in this study, 24-hourly fecal coliform concentrations where generated each day. To estimate the 30-day geometric mean from the hourly HSPF output, we took the running geometric mean of 720 hourly values (30 days * 24 hours/day = 720 hours).

Table 6.1. Annual precipitation during the TMDL allocation period.

Year	Precipitation, in	Deviation from Mean, %
Mean annual precipitation	42.0	___
1994	37.4	-11.0
1995	41.3	-1.7
1996	50.8	+21.0
1997	36.1	-14.0

6.2. Existing Conditions

Analyses of the simulation results for the existing conditions in the watershed for the 1994 to 1997 allocation period (Table 6.2) show that direct deposition of manure by cattle into the stream is the primary source of fecal coliform in the stream. Direct deposition of manure by cattle into Naked Creek is responsible for approximately 67.2% of the mean daily fecal coliform concentration. The next largest contributor is NPS loadings from upland pervious land segments (manure applied to cropland, pastures and forests by livestock, wildlife, and other NPS sources), which is responsible for 29.0% of the mean daily fecal coliform concentration. Direct deposits to streams by wildlife are responsible for 3.7% of the mean daily fecal coliform concentration and all other sources contribute less than 0.1%.

As shown in Table 6.2, direct fecal coliform loading by cattle in the stream result in much higher mean daily fecal coliform concentrations (2,106 cfu/100 mL) than nonpoint fecal coliform loadings from pervious upland areas (907 cfu/100 mL). The contribution of each of these sources to the 30-day geometric fecal coliform concentration is shown in Figure 6.1. As indicated in this figure, the 30-day geometric mean value is dominated by contributions from direct deposits of cattle to streams, and direct deposits by cattle alone result in almost continuous violation of the 30-day geometric mean goal of 190 cfu/100mL. In-stream fecal coliform concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected since cattle spend more time in streams during the summer months and because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. Figure 6.1 also shows that straight pipes and nonpoint source loadings from pervious land segments (PLS Only) are relatively minor, typically contributing a maximum of approximately 50 cfu/100mL to the 30-day GM value. In contrast, while direct deposits of wildlife alone do not violate the 30-day GM goal, they do contribute up to 160 cfu/100mL to the 30-day GM value. These high values for direct deposits from wildlife suggest that some reductions in wildlife loadings will be required in the final TMDL allocation.

Table 6.2. Relative contributions of different fecal coliform sources to the overall fecal coliform concentration for the existing conditions in the Naked Creek watershed.

Source	Mean Daily Fecal Coliform Concentration by Source, cfu/100mL	Relative Contribution by Source, %
All sources	3,131	
Direct deposits of cattle manure to stream	2,106	67.2%
Nonpoint source loadings from pervious land segments	907	29.0%
Direct nonpoint source loadings to the stream from wildlife	116	3.7%
Straight-pipe discharges to stream	3	0.1%
Nonpoint source loadings from impervious land use	<1	<0.1

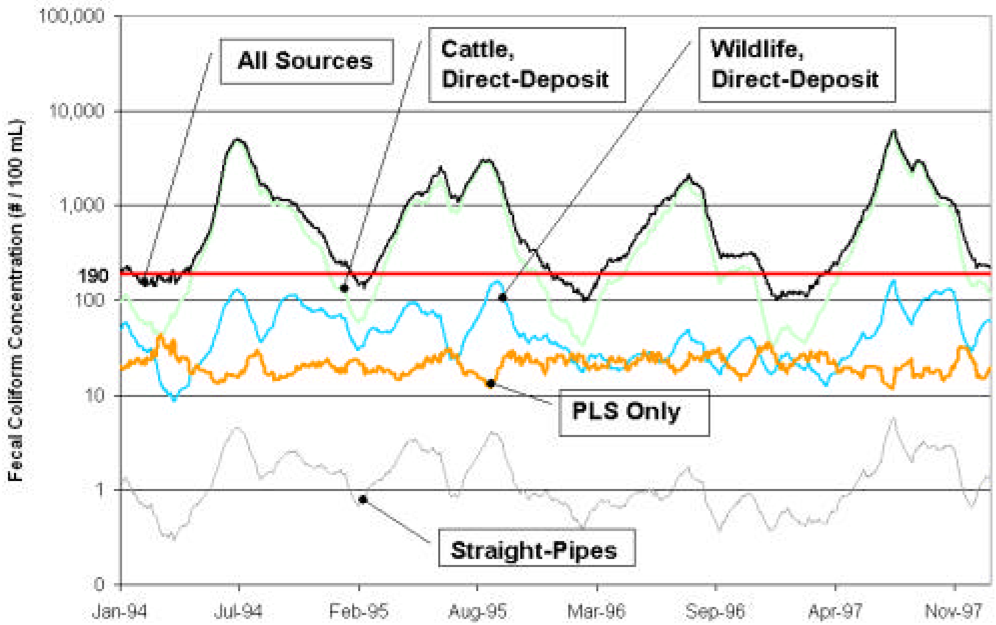

Figure 6.1. Relative contributions of different fecal coliform sources to the 30-day geometric mean fecal coliform concentration for existing conditions in the Naked Creek watershed.

6.3. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the TMDL goal of a 30-day geometric mean of 190 cfu/100mL. The scenarios and results are summarized in **Table 6.3**. Because direct deposition of fecal coliform by cattle into streams was responsible for 67% of the mean daily fecal coliform concentration (Table 6.2) and the vast majority of the 30-day geometric mean value (Figure 6.1), all scenarios considered required reductions in or elimination of direct deposits by cattle.

In all scenarios considered in **Table 6.3**, non-permitted straight-pipe contributions from on-site waste disposal systems were eliminated since these contributions are illegal under existing state law. Nonpoint source contributions from impervious land segments were neglected because their contribution to the 30-day geometric mean concentration is negligible (Table 6.2). In scenario 00, straight-pipes were eliminated and direct deposits by cattle to streams were reduced by 95% and 100%, but the 190 cfu/100mL 30-day geometric mean goal was still exceeded on 351 days or 24% of the time during the allocation period, indicating that reductions in other sources, wildlife direct deposits and NPS loadings from pervious land segments, would be required. However, the violation rate of 2.12%, which is within the MOS. In scenarios 02-05, reductions in direct deposits by cattle were held at 100% and NPS loadings from pervious land segments were reduced from 50 to 95%, and even with 95% reduction from pervious land segments, the TMDL goal was exceeded 0.41% of the time. Since it is not considered feasible to reduce NPS loadings by 75% to 95%, the 1-2% exceedance of the geometric mean standard is being addressed through reductions in direct deposits by wildlife. In scenarios 06 to 10, different combinations of reductions in direct deposits from cattle and wildlife and NPS loadings from pervious land segments were tried. Scenario 09, which required 100% reductions in direct deposits by cattle and straight-pipes, a 30% reduction in direct deposits by wildlife, and a 30% reduction in NPS loadings from pervious land segments, does not result in any violations and was selected for the final TMDL allocation. Additional scenarios with higher but reasonable reductions in NPS loadings from pervious land segments (up to 50%) were considered, but they did not result in 0 violations. Thirty-day geometric mean fecal coliform concentrations for the final TMDL allocation scenario (Scenario 09) as well as for the existing conditions are presented graphically in Figure 6.2.

Table 6.3. Allocation scenarios for Naked Creek watershed.

Scenario Number	Number of Violations of 190 cfu/100mL Goal	Violation Frequency, %	Required Reduction, %			
			Cattle Direct Deposit	Wildlife Direct Deposit	Straight-Pipes	NPS Loadings from Pervious Land Segments
00	351	24.02	95	0	100	0
01	31	2.12	100	0	100	0
02	24	1.64	100	0	100	50
03	24	1.64	100	0	100	60
04	20	1.37	100	0	100	80
05	6	0.41	100	0	100	95
06	20	1.37	100	10	100	0
07	12	0.82	100	15	100	0
08	3	0.21	100	25	100	0
09	**0**	**0.00**	**100**	**30**	**100**	**30**
10	1	0.07	99.5	45	100	30

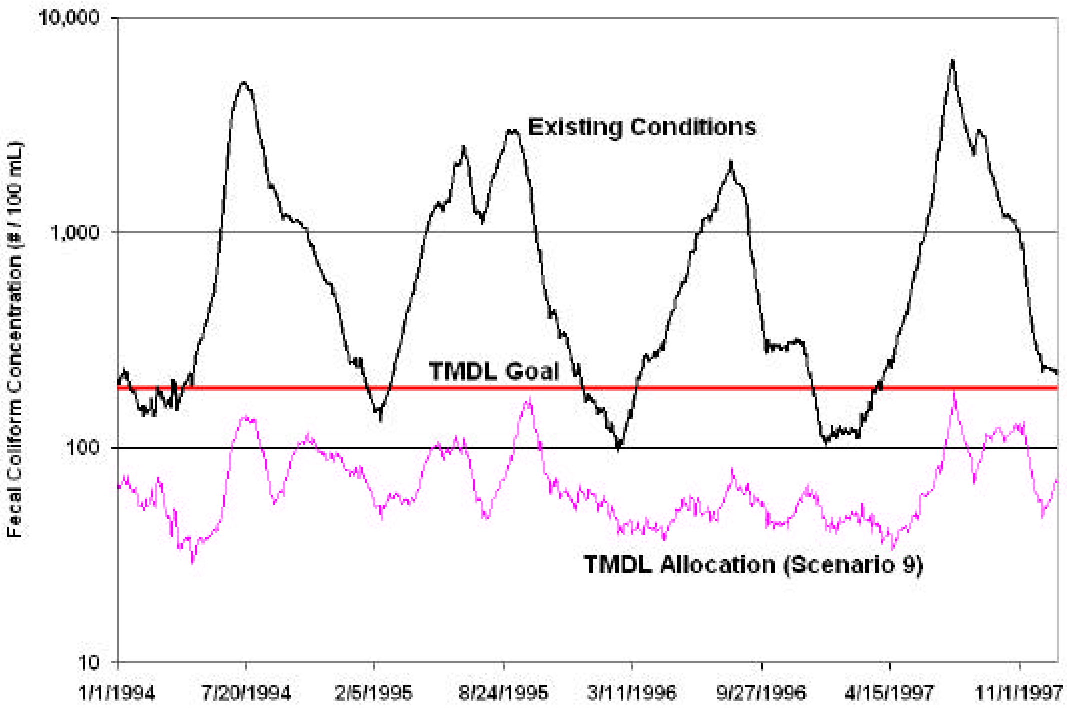

Figure 6.2. Existing conditions, 190cfu/100mL 30-day geometric mean goal, and successful TMDL allocation (Allocation Scenario 09 from Table 6.3**) for Naked Creek.**

Loadings for existing conditions and TMDL allocation scenario (Scenario 09) are presented for nonpoint sources by land use in Table 6.4 and for direct nonpoint sources in Table 6.5. From Tables 6.4 and 6.5, it is clear that nonpoint fecal coliform loading ($3,829 \times 10^{12}$ cfu/year) is nearly 123 times the loading from cattle depositing fecal coliform in the stream (31.1×10^{12} cfu/year). However, a comparison of Scenarios 01 and 05 (**Table 6.3**) reveals that nonpoint source fecal coliform loads are relatively minor since a 95% reduction in nonpoint source loads in Scenario 05 (compared 0% reduction in PLS loads in Scenario 01) results in a 1.71% decline in violations of the 30-day geometric mean. Cattle deposition directly in streams dominates stream water quality, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Though the BST data from Naked Creek is limited it also supports this conclusion. Loading from upland areas is reduced during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas will result in violations of the water quality standard. Since these upland loadings are intermittent, they are not a primary source of violations of the 30-day geometric mean standard.

Table 6.4. Annual nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 09).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	24.4	0.64%	17.1	30%
Pasture 1	1,976	51.62%	1,383	30%
Pasture 2	1,795	46.87%	1,256	30%
Residential[a]	31.7	0.83%	22.2[b]	30%
Forest	1.5	0.04%	1.5	0%
Total	3,829	100%	2,680	30%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

[b] Reduction only applies to Low Density Residential and Farmstead Areas (Not to High Density Residential Areas because the loadings from these areas were considered negligible)

Table 6.5. Annual direct nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 9).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	31.3	94.6%	0	100%
Straight-Pipes	0.6	1.8%	0	100%
Wildlife in Streams	1.2	3.6%	0.84	30%
Total	33.1	100%	0.84	97%

Based on the information provided in Tables 6.4 and 6.5, the total annual fecal coliform load from both nonpoint and direct nonpoint sources is 3,862 x 10^{12} cfu. The TMDL allocation load for both nonpoint and direct nonpoint sources added up to 2,681 x 10^{12} cfu, a reduction of 30% compared to the existing load. The load reductions by sub watershed are listed in Appendix G.

6.4. Summary of TMDL Allocation Scenario

A TMDL for fecal coliform has been developed for Naked Creek. The TMDL addresses the following issues:

1. The TMDL meets the water quality standard based on the 30-day geometric mean. After the plan is fully implemented, the geometric mean of fecal coliform concentration over any 30-day period will not exceed 200 cfu/100 mL.

2. The TMDL was developed taking into account all fecal coliform sources (anthropogenic and natural) from both point and nonpoint sources.

3. A margin of safety (MOS) of 5% was incorporated to ensure compliance of the geometric mean standard upon full implementation.

4. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Naked Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the 30-day geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions. Two out of the four years simulated were low flow years. A graph of the simulated stream flow for the allocation period is provided in Appendix H.

5. Both the flow regime and fecal coliform loading to Naked Creek is seasonal, with higher loadings and in-stream concentrations during summer. The TMDL accounts for these seasonal effects.

6. The selected TMDL allocation that meets the 30-day geometric mean water quality goal of 190 cfu/100 mL requires a 100% reduction in direct deposits of cattle manure to streams, elimination of all unpermitted straight-pipe discharges, a 30% reduction in direct deposits by wildlife to streams and a 30% reduction in nonpoint sources loadings from pervious

land segments. Using Eq. [6.1] and based on the TMDL allocation scenario selected (Scenario 09), the summary of the fecal coliform TMDL for Naked Creek is given in Table 6.6.

Table 6.6. Annual fecal coliform loadings (cfu/year) used for the Naked Creek fecal coliform TMDL.

Parameter	SWLA [a]	SLA	MOS [b]	TMDL
Fecal coliform	0.006×10^{12}	$2{,}681 \times 10^{12}$	141×10^{12}	$2{,}822 \times 10^{12}$

[a] Each point source contributed an equal amount to the WLA, therefore the WLA for each point source was 0.003×10^{12} cfu/year.

[b] Five percent of TMDL

CHAPTER 7: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

7.1. TMDL Implementation Process

This TMDL is the first step toward the expeditious attainment of water quality standards. The second step will be to develop a TMDL implementation plan, and the final step will be to implement the TMDL. Watershed stakeholders will have opportunities to provide input and to participate in development of the implementation plan, with support from regional and local offices of VADEQ, VADCR, VDH, and other participating assistance agencies.

The Commonwealth intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementation are:

1. as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved;

2. it provides a measure of quality control, given the uncertainties which exist in any model;

3. it provides a mechanism for developing public support;

4. it helps to ensure that the most cost effective practices are implemented first; and

5. it allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard.

7.2. Phase 1 Implementation Scenario for Naked Creek

The goal of the Phase 1 Implementation Scenario was to determine the fecal coliform loading reductions required to reduce violations of the instantaneous 1,000 cfu/100mL water quality standard to less than 10 percent.

During Phase 1 of the TMDL implementation plan, sampling for fecal coliform bacteria will continue until the violation rate of Virginia's instantaneous fecal coliform standard of 1,000 cfu/100 mL, is reduced to 10% or less. If the Phase 1 implementation plan fails to achieve the desired reductions within a reasonable period of time, additional reductions will be implemented to achieve the desired Phase 1 reductions. After the Phase 1 reduction in the fecal coliform violation rate is verified, subsequent phases of the TMDL implementation plan will begin.

For the implementation scenarios, HSPF was run with a 1-hour time step, as with the TMDL allocation scenarios, and the percentage of simulated hourly fecal coliform concentrations in excess of 1000 cfu/100mL was used to define the violation percentage. A margin of safety was not used in determining the Phase 1 Implementation Scenario. Several scenarios reduced violations to less than 10% (Table 7.1).

Table 7.1. Allocation scenarios for Phase 1 TMDL implementation for Naked Creek.

Scenario Number	Violation Frequency, %	Required Reduction, %			
		Cattle Direct Deposit	Wildlife Direct Deposit	Straight-Pipes	NPS Loadings from Pervious Land Segments
0	6.95%	95%	0%	100%	0%
1	17.98%	50%	0%	100%	0%
2	15.16%	60%	0%	100%	0%
3	11.25%	75%	0%	100%	0%
4	11.19%	75%	0%	100%	10%
5	10.01%	80%	0%	100%	10%
6	**9.71%**	**75%**	**0%**	**100%**	**20%**

The final scenario selected for Phase 1 implementation (Scenario 6) requires an 75% reduction in direct deposits by cattle to streams, a moderate reduction (20%) in nonpoint source loadings from pervious land segments (pastures, loafing lots, and cropland), and elimination of all straight-pipes. Reductions in wildlife deposits to the stream are not required. Loadings for the existing allocation and Phase 1 allocation scenario for nonpoint sources by land-use are presented in Table 7.2 and for direct nonpoint sources in Table 7.3. Fecal coliform concentrations resulting from Scenario 6 are presented graphically in Figure 7.1.

Table 7.2. Annual nonpoint source load reductions for Phase 1 TMDL implementation scenario for Naked Creek watershed (Scenario 06).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	24.4	0.64%	19.5	20%
Pasture 1	1,976	51.62%	1,581	20%
Pasture 2	1,795	46.87%	1,436	20%
Residential[a]	31.7	0.83%	23.4	20%
Forest	1.5	0.04%	1.5	0.0%
Total	3,829	100%	3,061	20%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

[b] Reduction only applies to Low Density Residential and Farmstead Areas (Not to High Density Residential Areas because the loadings from these areas were considered negligible)

Table 7.3. Required direct nonpoint source load reductions for Phase 1 Implementation Scenario (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	31.3	94.6%	7.8	75%
Straight-Pipes	0.6	1.8%	0	100%
Wildlife in Streams	1.2	3.6%	1.2	0.0%
Total	33.1	100%	9.0	73%

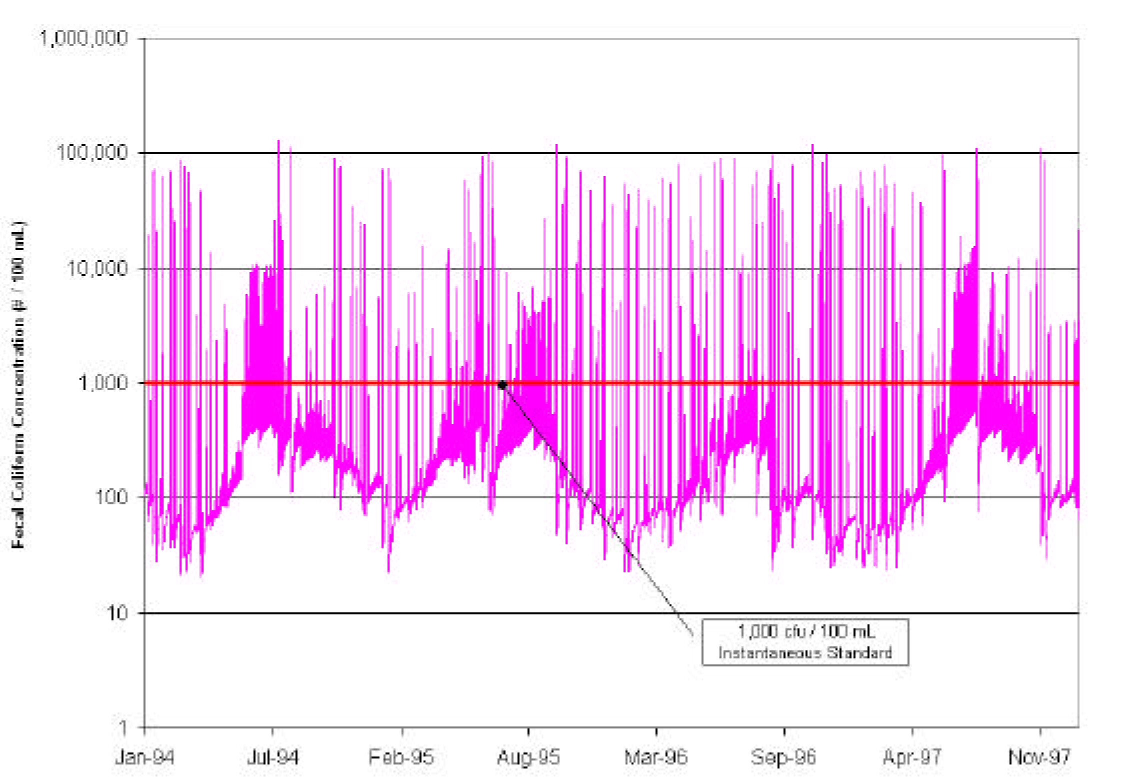

Figure 7.1. Phase 1 TMDL implementation scenario for Naked Creek.

7.3. Reasonable Assurance for Implementation

7.3.1. Follow-Up Monitoring

The Department of Environmental Quality will continue to monitor Naked Creek in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

7.3.2. Regulatory Framework

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "*develop and implement a plan to achieve fully supporting status for impaired waters*". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

7.3.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. An increasing proportion of Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA's Conservation Reserve Enhancement Program (CREP), the state revolving loan program and the Virginia Water Quality Improvement Fund. Each implementation plan will contain a reasonable assurance section that details the availability of funds for implementation of voluntary actions.

7.3.4. Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all the sources of fecal coliform (other than wildlife), the stream will not attain standards. As is the case for Naked Creek, TMDL allocation reductions of this size are not realistic and do not meet EPA's guidance for reasonable assurance. Based on the water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. This is obviously and impractical action. While managing over-populations of wildlife remains an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL. In such a case, after demonstrating that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs, the state may decide to re-designate the stream's use for secondary contact recreation or to adopt site-specific criteria based on natural levels of fecal coliform. The state must demonstrate that the source is natural and uncontrollable through a so-called Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the state's water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process.

Based on the above, EPA and Virginia have developed a TMDL strategy to address the wildlife issue. The first step in this strategy is to develop an interim reduction goal such as the one presented in Tables 7.2 and 7.3. The pollutant reductions for this interim goal are applied only to controllable anthropogenic sources identified in the TMDL, setting aside any control strategies for wildlife. During the first implementation phase, all controllable sources would be reduced to the maximum extent practicable using the staged implementation approach. Following the completion of this phase, VADEQ would re-assess water quality in the stream to determine if the water quality standard is being attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the second phase because the water quality standard exceedances attributed to wildlife in the model are very small and may fall within the margin of error.

CHAPTER 8: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. On June 6, 2001, members of the Virginia Tech TMDL group traveled to Augusta County to become acquainted with the watershed. During that trip, they spoke with various stakeholders. In addition a network was formed in which personnel from the Headwaters SWCD and NRCS visited watershed residents to acquire their input.

The first public meeting was public noticed on October 2, 2001 and held on October 25, 2001, at the Bethany United Methodist Church in Weyers Cave, Virginia to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates, and to discuss the hydrologic calibration. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 25 people attended the meeting. The public comment period ended on November 8, 2001.

The final public meeting was public noticed on February 7, 2002 and held on February 28, 2002 at the Fort Defiance High School in Fort Defiance, Virginia to present the draft TMDL report and solicit comments from stakeholders. Approximately 45 people attended the final meeting. Copies of the presentation materials were distributed to the public at the meeting. The public comment period ended on March 15, 2002. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA. Two comments were received by e-mail. No written response was required.

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APPENDIX A.

Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)
A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking
A collection of scientific methods used to track sources of fecal coliform.

Calibration
The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)
Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources
Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot} x_n$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model
Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source
Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen
Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source
Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution
Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach
Segment of a stream or river.

Runoff
That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system
An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation
The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe
Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)
The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff
Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)
Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)
The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

APPENDIX B.

Sample Calculation of Dairy Cattle
(Sub Watershed B28-10)

Sample Calculation: Distribution of Dairy Cattle

(Sub watershed (B28-10) during January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the dairy herd as presented in Table 4.7 is 42% milk cows, 8% dry cows, and 50% heifers.

Dairy cattle population			=	120
Milk cow population	=	120 * (42%)	=	50
Dry cow population	=	120 * (8%)	=	10
Heifer population	=	120 * (50%)	=	60

During January, milk cows are confined 75% of the time (Table 4.5). Dry cows and heifers are not confined.

Milk cows in confinement = 25 * (75%) = 38

When not confined, milk cows are on the pasture or in the stream. Dry cows and heifers are assumed to spend all their time on the pasture and in the stream.

Milk cows on pasture and in the stream =	(50 – 38)	=	12
Dry cows on pasture and in the stream		=	10
Heifers on pasture and in the stream		=	60

Seventy fifteen percent of the pasture acreage has stream access (Table 4.6). Hence dairy cattle with stream access are calculated as:

Milk cows on pastures with stream access	=	12*(15%)	=	2
Dry cows on pastures with stream access	=	10*(15%)	=	2
Heifers on pastures with stream access	=	60*(15%)	=	9

Dairy cattle in and around the stream are calculated using the numbers in Step 4 and the number of hours cattle spend in the stream in January (Table 4.5) as:

Milk cows in and around streams	=	2*(0.5/24)	=	0.04
Dry cows in and around streams	=	2*(0.5/24)	=	0.04
Heifers in and around streams	=	9*(0.5/24)	=	0.20

Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 4.2.2).

Milk cows defecating in streams	=	0.04*(30%)	=	0.012
Dry cows defecating in streams	=	0.04*(30%)	=	0.012
Heifers defecating in streams	=	0.20*(30%)	=	0.060

After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 6) from number of cattle in pasture and stream (Step 3).

Milk cows defecating on pasture	=	(2 – 0.012)	=	1.988
Dry cows defecating on pasture	=	(1 – 0.012)	=	1.988
Heifers defecating on pasture	=	(9 – 0.060)	=	8.940

APPENDIX C.

Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from the producer survey that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 (Section 4.2.4) for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [4.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.

3. The annual production of fecal coliform based on 'as-excreted' values (Table 2.4) was calculated for dairy manure.

4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of diary applied during that month based on the application schedule given in Table 2.10.

APPENDIX D.

Weather Data Preparation

Section Provided by USGS from Christians Creek FC TMDL

Rainfall data were obtained from the National Climatic Data Center. These data were collected hourly at the Staunton Sewage Treatment Plant (SSTP) rain gage that is located just to the West of the Christians Creek watershed. This rain gage has been operational since August 1, 1948. Average annual rainfall measured between 1991 and 1997 was 40.2 inches. The maximum annual rainfall amount during this period of 52.0 inches occurred in 1996 and the minimum annual rainfall amount of 35.1 inches occurred in 1991. The 30-year rainfall average at the SSTP gage is 41.1 inches (Climatological Data Annual Summary for Virginia 1999). Missing data in the hourly rainfall record were supplemented with data from 4 possible rain gages in and around the Christians Creek watershed, which are Sherando, Spottswood, Middlebrook, and Stoney Creek (Table C-1). These gages are part of the National Weather Service's Automated Flood Warning System for Augusta County, Virginia. Rainfall data gaps were primarily filled with data from the Middlebrook rain gage. The Middlebrook rain gage is the closest geographically to the SSTP. From 1991 – 1994, rainfall data from Spottswood were used when rainfall data from both SSTP and Middlebrook were missing. From 1995 – 1997, average rainfall from Spotswood, Sherando, and Stoney Creek were generally used when rainfall data from both SSTP and Middlebrook were missing.

Daily minimum temperature, daily maximum temperature, percent cloud cover, dew point temperature, and wind speed data were collected for the purpose of calculating potential evapotranspiration (PET) for the Christians Creek watershed (Table C-1). Daily minimum and maximum temperature data were collected from SSTP. Missing temperature data were supplemented by using temperature data collected at Dale Enterprise. Dew point temperature and percent cloud cover data were collected from the Lynchburg Regional Airport. The collection of percent cloud cover data at the Lynchburg Regional Airport ended June 1996. Percent cloud cover for the period July 1996 – December 1997 were obtained from Quantico MCAS. Wind speed data were collected from

Elkins – Randolph, Elkins, West Virginia. These data were required for calculating PET. Daily PET values were calculated using the Penman equation, which is part of the EPA software package WDMUtil (USEPA, 2001). The average of the annual PET values were compared and calibrated to average annual evaporation from a Class A Pan. A Class A Pan coefficient of 76% was applied, in the model, to the calculated PET values because values of evaporation from a Class A Pan generally over estimate actual evapotranspiration. Daily values of PET were disaggregated to hourly values using WDMUtil.

Table D-1. Meteorological data sources.

Type of Data	Location	Source	Recording Frequency	Period of Record	Latitude Longitude
Rainfall (in)	Staunton Sewage Treatment Plant	NCDC	1 Hour1 Day	1/1/73 – 12/31/998/1/48 – 12/31/99	38°10’52” 79°05’25”
Rainfall (in)	Sherando	NWS	1 Hour	4/1/91 – 12/31/99	37°59’45” 78°59’30”
Rainfall (in)	Spottswood	NWS	1 Hour	4/1/91 – 12/31/99	37°57’42’ 79°12’44”
Rainfall (in)	Middlebrook	NWS	1 Hour	4/1/91 – 12/31/99	38°02’54” 79°13’45”
Rainfall (in)	Stoney Creek	NWS	1 Hour	10/1/93 – 12/31/99	37°59’24” 79°07’22”
Min Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/99	38°10’52” 79°05’25”
Max Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/99	38°10’52” 79°05’25”
Min Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/99	38°27’19” 78°56’07”
Max Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/99	38°27’19” 78°56’07”
Cloud Cover (%)	Lynchburg Regional Airport	NCDC	1 Hour	8/1/48 – 6/30/96	37°20’15” 79°12’24”
Cloud Cover (%)	Quantico MCAS	NCDC	1 Hour	4/1/45 – 5/31/98	38°30’00” 77°18’00”
Dew Point Temp (°F)	Lynchburg Regional Airport	NCDC	1 Hour	1/1/48 – 6/30/96	37°20’15” 79°12’24”
Wind Speed (360° and knots)	Elkins-Randolph Elkins WV	NCDC	1 Hour	1/1/64 – 12/31/99	38°53’07” 79°51’10”

APPENDIX E.

Fecal Coliform Loading in Sub Watersheds

Table E-1. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B28-01 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	252	692,544	136,702	1,505	29,416
Feb.	114,516	631,178	124,582	1,408	27,518
Mar.	571,655	1,150,544	227,295	940	29,416
Apr.	457,366	1,111,713	219,624	910	28,467
May	114,533	1,145,221	226,242	940	29,416
Jun.	244	1,236,127	216,227	910	28,467
Jul.	252	1,272,612	223,434	940	29,416
Aug.	252	1,272,612	223,434	940	29,416
Sep.	244	1,391,452	218,944	1,457	28,467
Oct.	174,201	1,148,770	226,944	1,505	29,416
Nov.	174,193	1,113,430	219,963	1,457	28,467
Dec.	252	692,544	136,702	1,505	29,416
Total	1,607,960	12,858,747	2,400,094	14,419	347,302

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-2. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B28-02 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	1,223	336,616	927,730	2,179	37,506
Feb.	26,237	306,789	845,479	2,038	35,085
Mar.	126,688	559,305	1,542,776	1,049	37,506
Apr.	101,555	540,517	1,490,950	1,015	36,296
May	26,316	556,993	1,536,392	1,049	37,506
Jun.	1,184	564,149	1,470,356	1,015	36,296
Jul.	1,223	581,918	1,519,368	1,049	37,506
Aug.	1,223	581,918	1,519,368	1,049	37,506
Sep.	1,184	601,203	1,486,831	2,109	36,296
Oct.	39,418	558,534	1,540,648	2,179	37,506
Nov.	39,378	541,263	1,493,009	2,109	36,296
Dec.	1,223	336,616	927,730	2,179	37,506
Total	366,855	6,065,819	16,300,640	19,020	442,812

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-3. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B28-03 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	998	3,952,387	2,078,213	4,743	120,605
Feb.	51,365	3,602,056	1,893,883	4,437	112,823
Mar.	253,154	5,902,532	2,463,956	1,918	120,605
Apr.	202,690	5,704,493	2,382,963	1,856	116,714
May	51,429	5,878,862	2,459,274	1,918	120,605
Jun.	966	5,690,618	2,367,860	1,856	116,714
Jul.	998	5,878,223	2,446,788	1,918	120,605
Aug.	998	5,878,223	2,446,788	1,918	120,605
Sep.	966	5,814,183	2,379,942	4,590	116,714
Oct.	77,760	5,894,642	2,462,395	4,743	120,605
Nov.	77,728	5,712,128	2,384,473	4,590	116,714
Dec.	998	3,952,387	2,078,213	4,743	120,605
Total	720,050	63,860,734	27,844,749	39,229	1,423,915

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-4. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watershed B28-04 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	1,005	2,142,196	1,271,367	4,210	92,864
Feb.	64,615	1,952,342	1,158,638	3,938	86,870
Mar.	319,381	3,624,677	2,157,005	1,950	92,864
Apr.	255,674	3,545,326	2,109,871	1,887	89,868
May	64,680	3,659,145	2,177,596	1,950	92,864
Jun.	973	3,608,852	2,097,271	1,887	89,868
Jul.	1,005	3,714,872	2,167,180	1,950	92,864
Aug.	1,005	3,720,599	2,167,180	1,950	92,864
Sep.	973	3,704,615	2,107,351	4,074	89,868
Oct.	94,408	3,663,504	2,180,200	4,210	92,864
Nov.	97,894	3,507,752	2,087,424	4,074	89,868
Dec.	1,005	2,142,196	1,271,367	4,210	92,864
Total	902,619	38,986,077	22,952,453	36,291	1,096,392

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-5. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds B28-05,06 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	1,585	3,889,599	494,784	7,572	57,315
Feb.	45,729	3,544,886	450,913	7,083	53,616
Mar.	222,813	6,620,107	843,360	3,617	57,315
Apr.	178,516	6,484,574	826,115	3,500	55,467
May	45,831	6,682,314	851,301	3,617	57,315
Jun.	1,534	6,459,175	814,741	3,500	55,467
Jul.	1,585	6,654,602	841,899	3,617	57,315
Aug.	1,585	6,663,480	841,899	3,617	57,315
Sep.	1,534	6,585,268	823,840	7,328	55,467
Oct.	63,479	6,700,727	853,652	7,572	57,315
Nov.	68,881	6,406,555	816,155	7,328	55,467
Dec.	1,585	3,889,599	494,784	7,572	57,315
Total	634,658	70,580,886	8,953,443	65,924	676,691

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-6. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds B28-07 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^8 cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	23	1,626,375	32,776	2,974	11,945
Feb.	8,825	1,482,291	29,871	2,782	11,174
Mar.	44,042	2,700,377	54,473	1,279	11,945
Apr.	35,237	2,608,451	52,619	1,238	11,560
May	8,827	2,685,445	54,172	1,279	11,945
Jun.	22	2,571,189	51,646	1,238	11,560
Jul.	23	2,656,532	53,367	1,279	11,945
Aug.	23	2,656,532	53,367	1,279	11,945
Sep.	22	2,620,632	52,424	2,878	11,560
Oct.	13,423	2,695,400	54,373	2,974	11,945
Nov.	13,423	2,613,268	52,716	2,878	11,560
Dec.	23	1,626,375	32,776	2,974	11,945
Total	123,914	28,542,865	574,579	25,051	141,028

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-7. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds B28-08 of the Naked Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	122	3,899,145	2,915,448	4,249	26,915
Feb.	25,856	3,553,452	2,656,839	3,975	25,178
Mar.	128,832	5,390,046	3,210,351	1,989	26,915
Apr.	103,086	5,211,422	3,105,852	1,925	26,047
May	25,864	5,375,318	3,207,438	1,989	26,915
Jun.	118	5,195,807	3,096,455	1,925	26,047
Jul.	122	5,367,937	3,199,670	1,989	26,915
Aug.	122	5,367,937	3,199,670	1,989	26,915
Sep.	118	5,265,706	3,103,973	4,112	26,047
Oct.	39,304	5,385,136	3,209,380	4,249	26,915
Nov.	39,301	5,216,173	3,106,792	4,112	26,047
Dec.	122	3,899,145	2,915,448	4,249	26,915
Total	362,967	59,127,227	36,927,316	36,751	317,767

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-8. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds B28-09 of the Naked Creek watershed.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	163	1,266,441	446,200	2,141	30,640
Feb.	9,250	1,154,202	406,636	2,003	28,663
Mar.	45,649	2,104,674	742,047	1,011	30,640
Apr.	36,547	2,033,766	717,045	979	29,652
May	9,260	2,095,327	738,748	1,011	30,640
Jun.	158	2,014,885	706,404	979	29,652
Jul.	163	2,081,672	729,950	1,011	30,640
Aug.	163	2,081,672	729,950	1,011	30,640
Sep.	158	2,050,277	714,917	2,072	29,652
Oct.	14,010	2,101,558	740,947	2,141	30,640
Nov.	14,005	2,036,781	718,110	2,072	29,652
Dec.	163	1,266,441	446,200	2,141	30,640
Total	129,690	22,287,697	7,837,153	18,575	361,752

[1] Includes Farmstead, Low and High Density Residential Loads

Table E-9. Monthly nonpoint fecal coliform loadings to the different land use categories in the sub watersheds B28-10 of the Naked Creek watershed.

Month	Fecal Coliform loadings (x10^{8} cfu/month)				
	Cropland	Pasture 1	Pasture 2	Forest	Residential[1]
Jan.	195	2,703,544	1,028,001	2,291	58,671
Feb.	22,212	2,463,957	936,854	2,144	54,885
Mar.	110,341	4,550,203	1,731,490	1,161	58,671
Apr.	88,306	4,429,800	1,685,684	1,124	56,779
May	22,224	4,574,996	1,740,935	1,161	58,671
Jun.	188	4,448,609	1,681,143	1,124	56,779
Jul.	195	4,588,998	1,737,181	1,161	58,671
Aug.	195	4,592,435	1,737,181	1,161	58,671
Sep.	188	4,485,438	1,684,776	2,218	56,779
Oct.	31,615	4,577,460	1,741,874	2,291	58,671
Nov.	33,720	4,403,422	1,675,636	2,218	56,779
Dec.	195	2,703,544	1,028,001	2,291	58,671
Total	309,574	48,522,406	18,408,757	20,347	692,699

[1] Includes Farmstead, Low and High Density Residential Loads

APPENDIX F.
Biological Source Tracking (BST) Results for Expanded Categories

Table F-1. BST results for expanded source categories.

Date	Station	FC Conc. (cfu / 100 ml)	% Human	% Livestock	% Wildlife	% Poultry	% Cow	% Horse	% Sheep	% Deer	% Goose	% Unknown Wildlife
06/06/01	NC1	2,860	4.4%	56.0%	39.7%	0.0%	50.4%	5.6%	0.0%	10.0%	5.6%	24.1%
06/06/01	NC2	4,080	0.0%	72.6%	27.4%	10.9%	54.4%	7.4%	0.0%	17.4%	0.0%	10.0%
06/06/01	NC3A	2,030	5.7%	54.8%	39.5%	4.8%	42.9%	7.1%	0.0%	5.0%	9.8%	24.8%
06/06/01	NC3B	2,260	4.0%	56.8%	39.2%	0.0%	48.3%	8.5%	0.0%	14.3%	2.1%	22.8%
06/06/01	NC4	470	7.8%	54.5%	37.8%	0.0%	47.8%	6.7%	0.0%	16.7%	4.4%	16.7%
07/17/01	NC1	2,210	16.5%	46.5%	37.0%	0.0%	29.6%	14.8%	2.2%	19.6%	6.5%	10.9%
07/17/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/17/01	NC3	190	2.1%	66.6%	31.3%	0.0%	49.1%	17.5%	0.0%	17.0%	4.3%	10.0%
07/17/01	NC4	1,460	0.0%	60.0%	40.0%	0.0%	40.0%	17.9%	2.1%	17.5%	10.4%	12.1%
08/20/01	NC1	1,550	0.0%	69.6%	30.4%	2.1%	63.2%	4.3%	0.0%	0.0%	2.1%	28.3%
08/20/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/20/01	NC3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/20/01	NC4	345	28.8%	62.9%	8.3%	0.0%	62.9%	0.0%	0.0%	0.0%	0.0%	8.3%
09/28/01	NC1	790	8.8%	64.2%	27.1%	4.2%	38.8%	12.9%	8.3%	8.3%	8.3%	10.4%
09/28/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
09/28/01	NC3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
09/28/01	NC4	220	4.2%	72.5%	23.3%	0.0%	44.6%	15.0%	12.9%	5.0%	5.8%	12.5%
10/23/01	NC1	170	21.3%	70.2%	8.5%	0.0%	70.2%	0.0%	0.0%	2.1%	0.0%	6.4%
10/23/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/23/01	NC3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/23/01	NC4	296	29.7%	55.4%	14.9%	0.0%	44.0%	7.1%	4.3%	0.0%	4.3%	10.6%
11/26/01	NC1	351	20.8%	54.2%	25.0%	0.0%	43.7%	6.3%	4.2%	4.2%	0.0%	20.8%
11/26/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/26/01	NC3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/26/01	NC4	52	13.6%	55.9%	30.5%	0.0%	44.3%	2.7%	8.9%	5.4%	8.9%	16.2%
12/11/01	NC1	1,448	31.2%	35.4%	33.4%	8.3%	14.6%	12.5%	0.0%	4.3%	20.8%	8.3%
12/11/01	NC2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/11/01	NC3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/11/01	NC4	498	16.6%	33.4%	50.0%	6.3%	16.7%	10.4%	0.0%	0.0%	37.5%	12.5%

APPENDIX G.
Required Reductions in Fecal Coliform Loads by Sub Watershed – Allocation Scenario

Table G-1a. Required annual reductions in nonpoint sources in sub watershed B28-01 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	106,548	9.70%	74,584	30%
Pasture[1]	976,707	88.92%	683,695	30%
Forest	778	0.07%	778	0%
Residential[2]	14,374	1.31%	10,062	30%
Total	1,098,407	100%	769,119	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-1b. Required annual reductions in direct nonpoint sources in sub watershed B28-01 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	150,103	78.90%	0	100%
Wildlife in stream	5,944	3.12%	4,161	30%
Straight pipes	34,187	17.97%	0	100%
Total	190,235	100%	4,161	98%

Table G-2a. Required annual reductions in nonpoint sources in sub watershed B28-02 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	24,321	1.07%	17,025	30%
Pasture[1]	2,221,892	97.40%	1,555,325	30%
Forest	1,105	0.05%	1,105	0%
Residential[2]	33,797	1.48%	23,658	30%
Total	2,281,115	100%	1,597,112	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-2b. Required annual reductions in direct nonpoint sources in sub watershed B28-02 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	204,698	95.90%	0	100%
Wildlife in stream	8,754	4.10%	6,128	30%
Straight pipes	0	0.00%	0	100%
Total	213,452	100%	6,128	97%

Table G-3a. Required annual reductions in nonpoint sources in sub watershed B28-03 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	51,071	0.73%	35,750	30%
Pasture[1]	6,891,026	98.48%	4,823,718	30%
Forest	1,931	0.03%	1,931	0%
Residential[2]	53,297	0.76%	37,308	30%
Total	6,997,325	100%	4,898,707	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-3b. Required annual reductions in direct nonpoint sources in sub watershed B28-03 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	667,435	97.15%	0	100%
Wildlife in stream	19,606	2.85%	13,724	30%
Straight pipes	0	0.00%	0	100%
Total	687,041	100%	13,724	98%

Table G-4a. Required annual reductions in nonpoint sources in sub watershed B28-04 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	45,544	0.80%	31,881	30%
Pasture[1]	5,541,447	97.56%	3,879,013	30%
Forest	1,806	0.03%	1,806	0%
Residential[2]	91,273	1.61%	63,891	30%
Total	5,680,069	100%	3,976,590	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-4b. Required annual reductions in direct nonpoint sources in sub watershed B28-04 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	245,250	93.38%	0	100%
Wildlife in stream	17,380	6.62%	12,166	30%
Straight pipes	0	0.00%	0	100%
Total	262,629	100%	12,166	95%

Table G-5a. Required annual reductions in nonpoint sources in sub watershed B28-05,06 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	27,001	0.63%	18,901	30%
Pasture[1]	4,230,281	97.95%	2,961,197	30%
Forest	3,666	0.08%	3,666	0%
Residential[2]	57,777	1.34%	40,444	30%
Total	4,318,725	100%	3,024,207	30%

[1] Includes Pastures 1 and 2
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-5b. Required annual reductions in direct nonpoint sources in sub watershed B28-05,06 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	730,979	93.59%	0	100%
Wildlife in stream	32,982	4.22%	23,088	30%
Straight pipes	17,094	2.19%	0	100%
Total	781,055	100%	23,088	97%

Table G-6a. Required annual reductions in nonpoint sources in sub watershed B28-07 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	8,775	0.48%	6,142	30%
Pasture[1]	1,798,644	99.13%	1,259,051	30%
Forest	1,607	0.09%	1,607	0%
Residential[2]	5,445	0.30%	3,811	30%
Total	1,814,471	100%	1,270,612	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-6b. Required annual reductions in direct nonpoint sources in sub watershed B28-07 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	358,628	96.80%	0	100%
Wildlife in stream	11,863	3.20%	8,304	30%
Straight pipes	0	0.00%	0	100%
Total	370,491	100%	8,304	98%

Table G-7a. Required annual reductions in nonpoint sources in sub watershed B28-08 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	29,972	0.32%	20,981	30%
Pasture[1]	9,284,584	99.48%	6,499,209	30%
Forest	2,088	0.02%	2,088	0%
Residential[2]	16,172	0.17%	11,320	30%
Total	9,332,816	100%	6,533,598	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-7b. Required annual reductions in direct nonpoint sources in sub watershed B28-08 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	415,277	92.33%	0	100%
Wildlife in stream	17,406	3.87%	12,184	30%
Straight pipes	17,094	3.80%	0	100%
Total	449,777	100%	12,184	97%

Table G-8a. Required annual reductions in nonpoint sources in sub watershed B28-09 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	9,003	0.40%	6,302	30%
Pasture[1]	2,223,379	98.88%	1,556,365	30%
Forest	970	0.04%	970	0%
Residential[2]	15,154	0.67%	10,608	30%
Total	2,248,506	100%	1,574,245	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-8b. Required annual reductions in direct nonpoint sources in sub watershed B28-09 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	297,697	97.06%	0	100%
Wildlife in stream	9,016	2.94%	6,311	30%
Straight pipes	0	0.00%	0	100%
Total	306,714	100%	6,311	98%

Table G-9a. Required annual reductions in nonpoint sources in sub watershed B28-10 of the Naked Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	17,414	0.38%	12,190	30%
Pasture[1]	4,541,851	98.95%	3,179,295	30%
Forest	1,007	0.02%	1,007	0%
Residential[2]	29,631	0.65%	20,742	30%
Total	4,589,903	100%	3,213,234	30%

[1] Includes Pastures 1 and 2

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-9b. Required annual reductions in direct nonpoint sources in sub watershed B28-10 of the Naked Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	119,962	92.31%	0	100%
Wildlife in stream	9,998	7.69%	6,999	30%
Straight pipes	0	0.00%	0	100%
Total	129,960	100%	6,999	95%

APPENDIX H.

Simulated Stream Flow Chart for TMDL Allocation Period

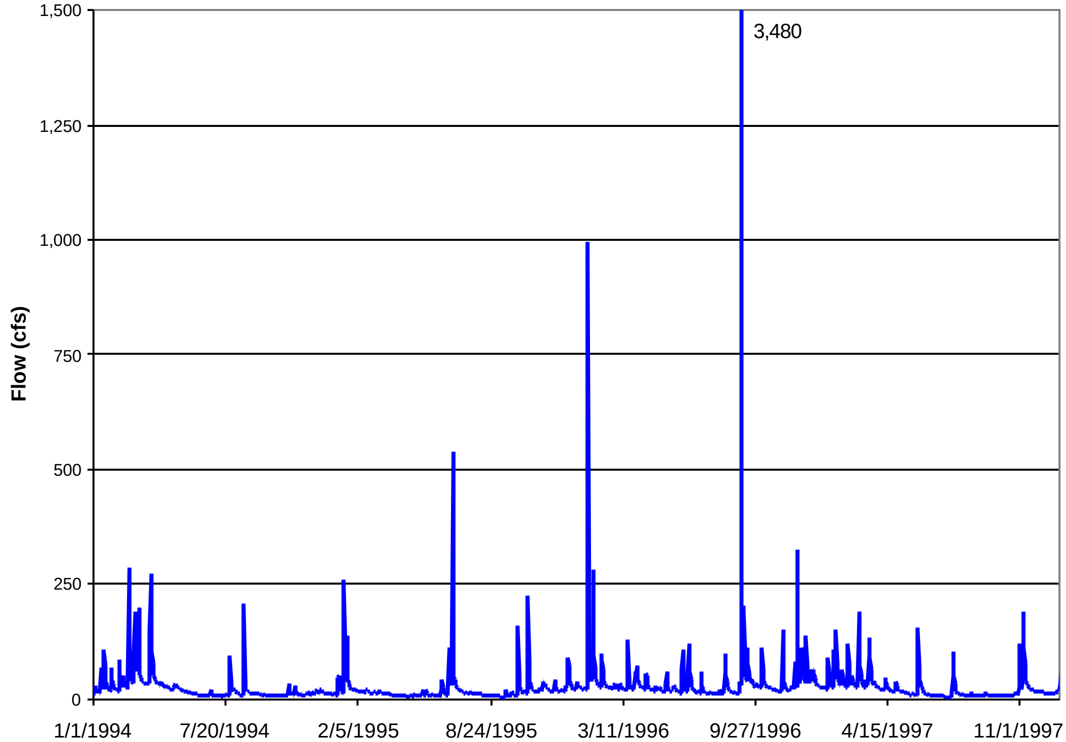

Figure H-1. Simulated Stream Flow for TMDL Allocation Period (1/1/1994 to 12/31/1997)

APPENDIX I.

Observed Fecal Coliform Concentrations and Antecedent Rainfall

Table I-1. Observed FC concentration and antecedent rainfall for Naked Creek

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
1BNKD000.80	07/30/1991	2,300	6.20
1BNKD000.80	02/25/1992	1,500	0.40
1BNKD000.80	08/26/1992	1,200	0.00
1BNKD000.80	12/07/1992	1,400	0.00
1BNKD000.80	02/18/1993	500	1.00
1BNKD000.80	06/10/1993	2,400	0.34
1BNKD000.80	07/19/1993	1,100	0.12
1BNKD000.80	08/26/1993	4,900	0.16
1BNKD000.80	09/16/1993	4,000	0.36
1BNKD000.80	10/26/1993	700	0.30
1BNKD000.80	11/16/1993	700	0.00
1BNKD000.80	12/14/1993	200	0.00
1BNKD000.80	02/14/1994	300	1.42
1BNKD000.80	03/23/1994	400	0.48
1BNKD000.80	04/19/1994	1,700	0.50
1BNKD000.80	05/10/1994	2,400	1.20
1BNKD000.80	06/20/1994	1,100	0.60
1BNKD000.80	07/18/1994	6,700	0.80
1BNKD000.80	08/15/1994	1,200	0.10
1BNKD000.80	09/29/1994	200	0.36
1BNKD000.80	10/20/1994	500	0.34
1BNKD000.80	11/15/1994	100	0.30
1BNKD000.80	12/06/1994	500	0.60
1BNKD000.80	01/19/1995	900	2.08
1BNKD000.80	02/28/1995	8,000	0.20
1BNKD000.80	03/29/1995	200	0.20
1BNKD000.80	04/24/1995	8,000	0.70
1BNKD000.80	05/30/1995	2,100	1.10
1BNKD000.80	06/26/1995	6,700	2.74
1BNKD000.80	07/20/1995	200	0.50
1BNKD000.80	08/15/1995	2,100	0.20
1BNKD000.80	09/19/1995	300	2.30
1BNKD000.80	10/18/1995	500	0.56
1BNKD000.80	11/13/1995	2,100	1.36
1BNKD000.80	12/11/1995	2,800	0.40
1BNKD000.80	02/05/1996	100	0.00
1BNKD000.80	03/28/1996	8,000	0.00
1BNKD000.80	04/25/1996	100	0.20
1BNKD000.80	05/15/1996	2,800	0.10
1BNKD000.80	06/24/1996	3,300	2.58
1BNKD000.80	07/18/1996	1,500	0.30
1BNKD000.80	08/20/1996	3,200	0.00
1BNKD000.80	10/10/1996	8,000	1.24

Table I-1. Continued

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
1BNKD000.80	11/13/1996	600	1.40
1BNKD000.80	12/19/1996	2,800	0.96
1BNKD000.80	01/22/1997	500	0.88
1BNKD000.80	02/18/1997	500	1.16
1BNKD000.80	03/27/1997	100	0.32
1BNKD000.80	04/29/1997	500	1.16
1BNKD000.80	05/28/1997	500	0.60
1BNKD000.80	06/19/1997	1,400	0.40
1BNKD000.80	07/31/1997	1,000	0.00
1BNKD000.80	08/07/1997	200	0.40
1BNKD000.80	09/29/1997	900	0.90
1BNKD000.80	10/14/1997	500	0.00
1BNKD000.80	11/20/1997	100	0.20
1BNKD000.80	12/17/1997	700	0.00
1BNKD000.80	01/15/1998	900	0.20
1BNKD000.80	02/18/1998	300	1.90
1BNKD000.80	03/26/1998	100	1.30
1BNKD000.80	04/30/1998	600	0.30
1BNKD000.80	05/19/1998	500	0.90
1BNKD000.80	06/15/1998	8,000	0.80
1BNKD000.80	07/29/1998	1,500	0.10
1BNKD000.80	08/20/1998	300	2.30
1BNKD000.80	09/21/1998	5,200	0.00
1BNKD000.80	10/01/1998	1,000	0.00
1BNKD000.80	11/23/1998	1,300	0.00
1BNKD000.80	12/21/1998	200	0.00
1BNKD000.80	01/27/1999	500	0.96
1BNKD000.80	02/25/1999	100	0.01
1BNKD000.80	03/31/1999	100	0.00
1BNKD000.80	04/21/1999	100	0.17
1BNKD000.80	05/19/1999	1,400	0.91
1BNKD000.80	06/22/1999	1,000	0.53
1BNKD000.80	07/29/1999	1,200	1.46
1BNKD000.80	08/12/1999	600	0.06
1BNKD000.80	09/29/1999	2,700	0.89
1BNKD000.80	11/29/1999	700	0.72
1BNKD000.80	12/20/1999	300	0.70
1BNKD000.80	02/24/2000	650	0.76
1BNKD000.80	03/28/2000	450	0.02
1BNKD000.80	04/24/2000	1,100	0.19
1BNKD000.80	05/31/2000	520	0.61
1BNKD000.80	06/20/2000	2,000	1.98
1BNKD000.80	07/27/2000	1,500	0.78

Table I-1. Continued

Station	Date	cfu/100mL	Total Rainfall for sampling day and preceding 5 days (inches)
1BNKD000.80	08/28/2000	2,000	0.41
1BNKD000.80	09/27/2000	2,000	1.26
1BNKD000.80	10/19/2000	2,000	0.01
1BNKD000.80	11/27/2000	320	0.41
1BNKD000.80	12/18/2000	2,000	2.07